ICE INVESTIGATIONS AT A BEAUFORT SEA CAISSON

1985

BY

K. R. CROASDALE AND ASSOCIATES LTD.

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1.0 BACKGROUND AND INTRODUCTION

In the Fall of 1984, K. R. Croasdale and Associates Ltd. (KRCA) initiated discussions with both industry and government concerning a possible field program around a caisson drilling structure in the Beaufort Sea.

Both the two candidate structures (the Gulf Molikpaq and the Esso CRI) were going to be monitored for ice loads and for internal structure and soil response. However, at neither structure was it planned to instrument the surrounding ice for ice pressures.

Furthermore, during the winter of 1983/84 Public Works Canada supported two projects[1,2] aimed at evaluating in-situ ice pressure sensors. These projects have led to a better understanding of the performance and accuracy of ice pressure sensors. However, in one of the projects it was the ice pressure panel mounted on the reaction structure which exhibited the most scatter and inaccuracy. It was mainly for this reason that KRCA suggested a modest program in which in-situ ice pressure sensors would be placed in the stable ice foot around a caisson and their readings compared to those from the ice load panels on the structure.

This type of program was of interest to industry, and both Gulf Canada Resources and Esso Resources Canada offered logistical support for such a project. The government of Canada was also interested in having an ice investigation program performed around a Beaufort Sea caisson and they responded positively to a proposal from KRCA in December, 1984. The arrangement agreed upon was that industry would provide logistical support and access to relevant data recorded by the structure monitoring system. The government of Canada would contract KRCA to rent the necessary in-situ ice sensors and data acquisition system, and to conduct the study using manpower supplied by the National Research Council of Canada and Public Works.

Both Gulf and Esso were agreeable to the study being conducted at their caissons. However by late January the ice conditions around the Gulf caisson were such that there was neither a stable ice foot nor a stable rubble field. Whereas a stable rubble field had formed around the Esso caisson at the Amerk location. Therefore the Esso caisson was the only possible location for this study. Limited accommodation at the rig however, did not allow mobilization to proceed until February 21, 1985.

The contract from the government of Canada required that the field program be completed by the end of March, 1985. Additional funding however was supplied by the U.S. Department of the Interior, Minerals Management Service, and this allowed the field monitoring to continue until early May 1985.

2.0 SUMMARY

A research project on ice pressures was conducted during the winter of 1984/85 at the Esso Caisson Retained Island at the Amerk drilling location in the Beaufort Sea. The island was situated in 26 m of water and was subject to significant ice movement during the course of the winter. This ice movement created a large grounded ice rubble field around the structure.

The major objectives of the study were:

(1) To measure typical ice pressures acting on and within the grounded ice rubble field,

(2) To characterize the ice rubble in terms of geometry and deformation and assess how the ice loads were transmitted through the grounded ice rubble.

(3) To compare the in-situ ice pressures in the ice rubble with those measured by the load cells on the caisson.

The scope of the study was limited by funding so that only the south and east sections of the rubble field were instrumented with seven in-situ ice pressure sensors. The period of the field program was from February 22 to May 15, 1985. The actual monitoring period for the instruments was from March 20 to May 5, 1985.

The rubble field was heavily grounded, especially at its

periphery. Ice pressures acting on the edge of the ice rubble during the period reached 200 kPa. The ice pressure events appeared to be caused by thermal expansion of the ice between the shore and the island.

Within the ice rubble, measurements of in-situ ice pressure indicated negligible transmission of lateral ice loads to the caisson. The load cells on the caisson also showed negligible ice forces during the monitoring period. Furthermore, the surveys of the ice rubble also indicated negligible lateral deformation. It is concluded that the ice forces were transmitted through the grounded ice rubble to the underwater berm of the island.

Stresses through the thickness of the consolidated zones in the ice rubble (typically 2 - 3 m thick) were complex and also appeared to be of thermal origin.

Because of the negligible lateral ice forces transmitted through the ice rubble it was not possible to sensibly compare caisson load cell readings with the in-situ ice pressures measured in the adjacent ice rubble.

3.0 TECHNICAL ISSUES ADDRESSED BY THE PROJECT

Artificial islands, caisson retained islands, and monolithic caisson structures are not easily instrumented to measure ice forces. Yet, reliable measurements of ice loads on these structures is desirable for two reasons:

(1) To enhance the safety of operations conducted from the structure by indicating the level of ice loads being applied.

(2) To provide a calibration of ice load prediction methods which can then lead to use of the structure in more severe ice environments, and also provide improved methodologies for optimization of future structures (especially for oil production).

The methods used to assess ice loads acting on artificial islands (and the response of these islands to the ice loads) were developed in the mid-1970's. The early Esso Canada artificial islands provided the stimulus for the development of specialized instruments for both ice pressure[3] and soil response[4].

The general approach to measure ice loads was to install in-situ ice pressure panels in the landfast ice surrounding these islands[5,6,7,8]. The global ice load on the island was then obtained from individual ice pressure readings by calculating ice pressure distributions in the surrounding ice and obtaining a transfer function between ice pressure at the sensor locations and ice load on the island. In the landfast ice it was generally possible to place sensors in the uniform first-year ice surrounding the ice rubble. The ice load obtained was that applied to the island/ice rubble combination. It was recognized that the grounded ice rubble would probably transmit ice loads directly into the underwater slopes of the islands, and the load applied to the island at the ice-line was generally unknown.

With the introduction of caisson-retained islands it became possible to instrument the caissons at the ice-line so that ice loads on them could be measured. The first caisson structure in the Beaufort Sea was the Tarsiut Island; the north and east caissons were instrumented for ice forces[9]. A combination of devices were used, including ice load panels of various types and also strain gauges in the diaphragms of the caissons. During the two years of monitoring at Tarsiut, in-situ ice panels were also deployed in the surrounding rubble field. Also strain meters were installed completely around the island on the surrounding first-year ice[10]. None of the data obtained at Tarsiut have yet been made public. However, a paper published by Pilkington et al did indicate that despite the grounded rubble surrounding the island, ice loads were being transmitted through it to the caissons.

Since Tarsiut, the Dome SSDC, the Esso CRI and the Gulf

Molikpaq in the Canadian Beaufort, and the Global Marine CIDS structure in the Alaskan Beaufort, have all been instrumented using ice pressure panels and/or load cells mounted at the ice-line; and also in some cases with in-situ ice panels in the surrounding ice.

In-situ ice sensors have been the subject of many development and performance studies. The main issues being to have a sensor which does not disturb the ambient stress (or at least if it does, that it be by a constant and known amount); and also that the output from the sensor be insensitive to the creep deformation of the ice. Metge et al[3] first discussed the required properties of a panel-type sensor and this was in parallel with Esso Canada's development of such a device in the mid-1970's. Others followed this lead and several improved sensors have been developed during the past decade. As referred to in the Introduction, a comprehensive evaluation of various in-situ ice pressure sensors was carried out by KRCA during the winter of 1984/85[2]. In total, 10 different types of ice sensors were tested in a large outdoor ice basin under known load conditions. Both long-term and short-term loads were applied during the 22 separate tests conducted. This project provided added confidence and qualification to the ability to interpret in-situ ice stresses from such devices. During the course of the study however it was noted that the ice pressure panel which was mounted directly on the reaction structure exhibited scatter and inaccuracy. This behaviour could have been due to some aspect of the test method and/or the particular sensor performance. Nevertheless the issue of how surface mounted ice load panels perform in terms of overall accuracy in a real ice environment had not (to this author's knowledge) been evaluated. The issue being whether load might be attracted to a panel if it was very stiff and protruded from the structure surface, or whether "bridging" might occur if the panel was less stiff than the structure.

Therefore, the rationale behind the original initiative for this project was that several current structures in the Beaufort Sea were extensively instrumented with ice load panels; that the performance of these panels in a real ice environment had never been evaluated; yet their readings were important to both drilling operations and future designs. At the same time, a high confidence level in interpreting in-situ ice pressure panels had been established by the 1983/84 KRCA project in the Esso ice basin. The original proposition for this project was to install in-situ ice pressure sensors opposite and adjacent to the load cells on the structure and compare their readings.

As planning for the project matured it was realized that the ice rubble field at the selected location was heavily grounded. This led us to be concerned that negligible ice forces might be transmitted through the ice rubble. Additional objectives were therefore developed which would address the transmission of ice forces from the edge of the ice rubble into its interior. The intent being to use such measurements to help calibrate theoretical models for this phenomenon.

4.0 STUDY OBJECTIVES

The objectives for the study which address the technical issues just discussed can be defined as:

(1) To measure typical ice pressures acting on and within a grounded ice rubble field around an arctic caisson structure.

(2) To characterize the ice rubble in terms of extent, geometry, consolidation and deformation, and assess how the ice loads were transmitted through the ice rubble.

(3) To compare the in-situ ice pressures in the ice rubble with those measured by the load cells on the caisson.

5.0 SCOPE OF THE STUDY

The scope of the study was limited in terms of both time of monitoring and extent of equipment deployed, by a finite relatively small budget. This allowed the rental of only seven ice pressure sensors and a data acquisition system for a period of three months. Obviously to completely encircle an arctic caisson with ice pressure sensors in sufficient numbers to address the previously defined objective, would have required considerably more equipment than was available. Therefore it was decided to concentrate the measurements on a sector of the rubble field. A 15 to 30° sector was imagined during the planning phase, but as will be described later in this report, the practical realities of the geometry of the rubble field caused a modification to concentrating all the instruments in such a narrow sector.

The scope of the study can be defined in terms of six separate tasks:

Task 1: Planning and Assembly of Equipment

This task involved liaison with both NRC and industry personnel to work out specific details of the project. Also it involved discussions with equipment suppliers and the arrangement of rental contracts for the sensors, the data acquisition system and other equipment.

At the end of this task a decision was made on the basis of ice conditions prevailing as to which structure would be the location for the study (the Esso CRI was selected).

Task 2: Mobilization and Field Installation

In this task, the contractor together with NRC and DPW personnel travelled North to the site and installed the equipment. A preliminary visual survey of the rubble field was carried out to determine the sensor locations (in conjunction with Esso personnel). Also eight survey posts were installed and an initial survey of the rubble field was performed using an electronic distance meter.

Task 3: Data Recording and Preliminary Analysis

During the period from installation to removal of equipment the data tapes were periodically changed and sent to NRC for reading and preliminary analysis. Esso personnel on site provided this service, and also conducted a daily manual check to ensure that the data acquisition system was functioning.

Task 4: Demobilization

At the end of the monitoring period, just prior to break-up, the equipment was removed and demobilized. At this time a second rubble survey was performed to give information on rubble movements. Also some limited ancillary measurements, such as rubble consolidation, were made.

Task 5: Data Processing and Analysis

During this task the readings of the data tapes were completed and the values obtained were analyzed. Comparisons of in-situ ice pressure readings were made with readings supplied by Esso of the ice load panels on the caissons. Also the transmission of load through the rubble field was examined, and qualified with ice rubble survey data and consolidation and grounding measurements.

Task 6: Report

During this task the report for the project was assembled.

6.0 THE ESSO CRI AND INSTRUMENTATION

The arrangement of the Esso Caisson Retained Island is shown in Figure 1. It consists of eight steel caissons, each with a mass of 5000 tonnes, which can be assembled in the form of a ring. The eight water-ballasted caissons are held together with steel cables, the interior of the ring is filled with sand ballast which provides the sliding resistance and support for the rig. After an exploratory well has been drilled, the rig can be removed, and by slackening the steel cables the caissons can be deballasted and re-used at another location. A more complete description of the system is given in Appendix A. During the 1983/84 winter the CRI was located at Kadluk in about 15 m of water. The location of the CRI for this study was Amerk in 26 m of water (Figure 2). At the Amerk location, the CRI sat on a subsea berm built to within 9 m of sea level; a drawing of the berm geometry is given in Figure 3.

The CRI is instrumented with a variety of ice load panels, strain gauges and soils instruments; these have been described by Hawkins et al[11]. The arrangement of the ice load sensors is shown in Figure 4.

A description of the data acquisition system by C. Y. Der is provided in Appendix A.

7.0 OVERVIEW OF ICE CONDITIONS AROUND THE CAISSON

The Amerk location in 26 m of water is just beyond the normal boundary of the landfast ice. However the landfast ice boundary, as shown in Figure 5, does vary from year to year. Furthermore the presence of an island can create a temporary extension of the landfast ice. This does not seem to have occurred at Amerk, the ice being mobile throughout the winter (although the ice to the south of the island was undoubtedly more stable than the ice to the north).

Ice rubble started to ground around the CRI early in the winter, Figures 6 to 8 show aerial photographs of the island and rubble field at various times throughout the winter. Figure 9 shows a map of the ice rubble just prior to sensor installation.

Throughout the winter the ice moving against the CRI and its rubble field was first-year.

During the period of sensor deployment ice conditions within the rubble field, and the extent of the grounded rubble, did not change significantly.

8.0 SENSORS AND INSTRUMENTATION USED IN THE PROJECT

The following is a list of sensors used in the project:

- 3 Arctec Hexpack ice load panels, each 0.5m x 2m with ice pressure profiling capability (normal to panel).
- 2 Exxon panels, 0.4m x 2m, configured to measure average ice pressure applied (normal to panel).
- 1 Weir-Jones Ideal panel 1m x 1m, configured to measure average ice pressure applied (normal to panel).
- 1 CMEL Mark IV C Hexagonal sensor, 8cm across by 18cm long, configured to measure biaxial ice stress at one level in the ice sheet.

Figures 10 to 13 show photographs of these sensor types.

The data acquisition system used was the Arcdats 1 consisting of a slave unit on the ice which was hard-wired to a master recording unit installed in a warm environment on the CRI.

Descriptions of the sensors and the data acquisition system are given in Appendix B.

9.0 SENSOR LOCATION, INSTALLATION AND REMOVAL

Sensor installation took place between February 21 and 27, 1985. The locations chosen for the sensors are shown in Figure 14. Table 1 gives the key to sensor numbering and the coordinates referenced to the CRI caissons. Removal of the sensors took place May 13 to May 17, 1985.

An immediate dilemma on arriving at the site was the question of where to deploy the sensors. The North and N.E. caissons are the most heavily instrumented (see Figure 4). Prior to arrival at the site, a review of rubble field features (see Figure 9) suggested a possible deployment of most of the sensors in a sector off the N.E. caisson where the rubble appeared to be low.

However, closer inspection of the rubble indicated virtually no flat spots off the N.E. caisson. Furthermore, the very high grounded rubble at the perimeter (10-15m) gave us concern that ice loads transmitted through to the caisson might be negligible. On the other hand, there were several flat spots in the rubble off the S.E. caisson. Furthermore, although the perimeter rubble was also high, it was expected that in the spring, loads from the south due to thermal expansion of the landfast ice might be significant. Therefore, the S.E. was the area chosen for the deployment of most of the sensors, see Figure 14.

The exceptions were as follows:

- Sensor 1 (an Arctec Hexpack) was deployed off the N.E. caisson in a "flat spot" opposite a "shear-bar" load cell on the caisson. This location was the only "flat spot" off the N.E. caisson and some removal of ice blocks was necessary in order to enlarge the flat area prior to sensor installation. A major rationale for installing this sensor was that none of the other caissons on the east or south side had operational shear-bar load cells.

- Sensor 7 (an Exxon panel) was deployed close to the south edge of the rubble in an area which appeared to be ungrounded. It was hoped that this sensor would record typical ice loads imposed by the ice at the edge of the rubble field (prior to any absorption of load by grounded features). Ideally this sensor should have been installed at the S.E. edge of the rubble along a radial line from the inner sensors. However no suitable location could be found in the S.E. sector (the edge of the rubble was too steep). Conversely one of the inner sensors should have been placed on a line between sensor 7 and the south caisson. But, no suitable location in the rubble on the south side could be found (primarily because flaring had disturbed the ice).

As already mentioned, five sensors were deployed in the ice off the S.E. caisson (Figure 14). Three sensors of different types (Hexpack, Ideal and CMEL Mark IV) were installed close to the load instrumentation at the north end of the S.E. caisson. Another Hexpack was placed about 20 m further out on the same radial line. For comparison an Exxon panel was placed a similar distance out from the caisson but further south.

The locations chosen were all in relatively flat areas but installation was not easy. Air temperatures were in the range 0 to -35° C during the period and equipment such as chain saws didn't work too well. Also the thickness of the consolidated zone was generally greater than 2 m, so installation of the long panel sensors required removal of a lot of ice. Because of chain saw problems most panels were installed using auger and chisel. This required the mining of about 3 tons of ice per installation. Some panels were not installed to their full depth because of these difficulties. In addition to equipment problems we were also plagued with polar bears; their presence prevented us from working outside the caissons on several occasions. Figures 15 to 17 show photographs of sensor installation.

We also had problems with our data acquisition system. This was an Arctec Arcdats system rented for the project. It consisted of a slave unit on the ice which was hard wired to a master recording unit installed in one of the heated control rooms on caisson 3. Although both units appeared to be functioning prior to shipment from Calgary, our technician had problems trying to set-up the system in the North. We finally had to bring the slave unit out for checking by Arctec; they replaced several faulty components.

All this of course took time, so that we didn't actually get the system operating properly until March 20. We demobilized during the period May 13 to 17, but some minor melt pool flooding caused the system to malfunction on about May 5, 1985.

In addition to the d.a. problems, two sensors malfunctioned, the CMEL Mark IV biaxial sensor and the Weir-Jones Ideal panel. After installation the balance points seemed to drift randomly. It was later found that the Ideal panel had a leak. The other five sensors all appeared to function satisfactorily.

For sensor removal, a steam wand, supplied through steam hoses from the rig steam generator, was used. This worked extremely well and all sensors were removed during two long working days. Figure 18 and 19 show photographs of sensors during removal.

10.0 DATA REDUCTION AND SUMMARIES OF SENSOR AND ICE LOAD PANEL READINGS

The National Research Council of Canada undertook the reading and plotting of the data tapes. The results plotted in engineering units for each of the operating sensors are shown in Figures 20 to 50.

For the same period Esso Resources Canada Ltd. supplied the readings obtained from the CRI load cells. For each day, a set of readings similar to the sample shown in Table 2 was provided. The daily values for the load cells which faced sectors of the ice rubble where in-situ were placed, are shown in Table 3 for the monitoring period.

11.0 ANCILLARY MEASUREMENTS AND OBSERVATIONS

Meteorological data for the monitoring period are summarized in Table 4. Included are wind speed and direction, air temperature, barometric pressure and overhead conditions.

Eight survey posts were installed in the east sector of the rubble field and on which reflectors could be placed for distance measurements from a fixed point on the heli-deck. Surveys were made on February 24, May 13 and May 15. The results of these surveys are given in Table 5.

Profiles of the rubble field heights were obtained from stereo-aerial photographs along three selected lines covering the north-east, east, and south-east sectors of the rubble field. These profiles are shown in Figure 51 to 53. The approximate position of the survey lines are shown on Figure 54.

The water depths over the underwater berm were obtained by Esso shortly after construction, these are shown in Figure 55.

Consolidation thicknesses in the ice rubble measured during sensor installation were generally greater than 2 m, but less than 3 m.

During sensor removal, four holes were drilled and logged for consolidation and ice thickness, the results obtained are given in Table 6.

12.0 DATA ANALYSIS AND DISCUSSION OF RESULTS

Although this project was limited in scope, both in terms of numbers of sensors and period of monitoring, there is in fact a considerable amount of data which could be analyzed in relation to ice pressures within a grounded rubble field. This report will provide some limited data analysis and discussion, but the raw data provided will also allow the reader to conduct more in-depth analysis if required. The analysis and discussion provided here will concentrate on examining the results in terms of the project objectives which were:

(1) To examine the distribution of ice pressures within a grounded ice rubble field around an arctic caisson structure.

(2) To compare in-situ ice pressures with those recorded on the caisson.

(3) To document the ice rubble geometry, movements, etc.

To examine the distribution of ice pressures within the ice rubble it is instructive to firstly look at the two Esso panels (sensors 6 and 7). These sensors averaged the compressive ice pressure across their area and also functioned well during the monitoring period. As expected, sensor 7 (Esso panel 103), which was the closest to the edge of the ice rubble, showed the highest ice pressure events. These are documented on the plots of ice pressure versus time shown on Figures 20 to 24. During the period March 20 to April 1st, ice pressures were close to zero except for a 50 kPa event on March 22 (day 3). Note that before and after any ice pressure event the signal returns tc zero, this essentially confirms that the zero is a true zero. (Which is an important point because zeros before freezing in and after removal were not obtainable because of initial problems with the d.a. system, and then flooding of a junction box just prior to removal.)

As shown on Figure 21, on April 1st, a significant ice pressure event occurred with subsequent peaks up to about 200 kPa (30 psi). In this context, "significant" implies some "apparent real activity", rather than a "significantly high value"; recognizing that most offshore platforms in the Beaufort Sea are designed for much higher ice pressure values (e.g. typically 1750 kPa ice pressure). This sensor continued to show clearly defined events of about 200 kPa pressure up to the end of the monitoring period on May 4th. Furthermore, in the latter part of the period, there was a distinct daily cycling of ice pressure from zero to some peak value (similar from day to day).

A similar cycling phenomenon and similar values of ice pressure were recorded by Johnson et al around the CRI at the Kadluk location the previous winter[12]. They suggested that the cycling of ice pressure was in response to diurnal fluctuation in air and ice temperatures. The evidence collected at Amerk supports the suggestion that ice pressures on the shoreward side of the island are of a thermal origin. Certainly there is no strong correlation with winds, as Figure 56 illustrates. On the other hand, as Figure 56 also illustrates, there is quite a strong correlation between the beginning of ice pressure events and significant temperature increases.

A plausible mechanism for these observations would be simple thermal expansion of the landfast ice between the shore and the island. Such a case was examined by Sanderson[13]. He calculated a 1.7 m/day movement as being typical for an island 50 km offshore, and 2 m thick ice. He further calculated, using indentation creep analysis that the associated ice pressure could be typically about 1 MPa for compressive in-plane deformation. Our observed pressure peaks were of course much less (0.2 MPa). But the failure mode at the edge of the rubble was not in-plane crushing but out-of-plane flexure (rubble building). That such events occurred is shown dramatically by comparing the ice conditions at sensor 7 on installation (Figure 16) with removal (Figure 19). As can be seen, there was a significant rubble building event which almost caused the destruction of the sensor. The thickness of the ice piece which had been pushed up was approximately 1.5 m.

The ice pressures generated on sensor 7 at the edge of the ice rubble appear to be real ice loading events associated with out-of-plane failure of relatively slow moving ice. The next issue to examine is whether these ice loads have been transmitted to the interior of the rubble and/or to the caisson itself. The closest ice sensor in the interior of the ice rubble was the other Esso panel, sensor 6 see Figure 14. This was not directly in-line with sensor 7, but should have responded if ice pressures on the outside of the rubble in the south east sector were being transmitted to the caisson. The output from sensor 6 is shown in Figures 25 to 29. As can be seen, for the whole period the ice pressures experienced by this sensor were essentially zero.

Furthermore, if we look at the load cells on the caissons which faced south or south-east, the changes in ice pressures were also very small (see Table 3). What changes did occur on the load cell readings cannot be correlated with the ice pressure events measured by sensor 7. (The variation shown in the load cell readings are possibly due to a number of causes including slight settlements of the rubble, electronic perturbations, thermal effects, etc.).

It must be concluded therefore that the ice pressures experienced by sensor 7 on the south edge of the ice rubble were not transmitted to the caisson. Presumably the ice forces were transmitted via grounded rubble into the underwater berm of the island. This is not unexpected given the large areas of high sails in the rubble field shown in Figure 9 and confirmed by the profiles obtained by stereo photography (Figures 51 to 53).

Treating the ice rubble as a granular material with a friction angle ϕ the short-term sliding resistance of grounded rubble can be expressed as[14];

$$q = (1-c)[h_m \rho i + y(\rho i - \rho w)] \tan \phi$$

where: q is the sliding shear resistance of the rubble per unit area

c is the average porosity of the rubble

h_m is the mean height of the rubble above sea level

y is the water depth

ρi is the ice weight density

ρw is the water weight density

Typically c is about 0.3 and ϕ might be in the range 30 to 45o. For a typical pile-up around the edge of the ice rubble field (Figure 9) we can assign values as follows:

h_m = 8 m

y = 15 m

then q = 24 kPa

For a typical radial width of, say, 50 m for a high pile-up, then the resistance expressed as an ice pressure in 1.5 m of ice can be calculated as:

$$PR = \frac{q \times 50}{1.5} = \frac{24 \times 50}{1.5} = 800 \text{ kPa}$$

Thus it is not surprising that the typical ice pressures of 200 kPa measured at the edge of the rubble field are not transmitted beyond the peripheral pile-ups.

Whilst the net compressive ice forces within the rubble field appear to be zero, an examination of the Hexpack outputs reveals additional complexity in the ice pressure distribution through the ice thickness. The Hexpack panels were wired to measure the ice pressure distribution through the ice thickness. Outputs from these sensors (Figures 30 to 45) show very complex ice pressure distributions through the ice thickness. In many cases it appears as though there is compression in the upper part of the ice sheet and tension in the lower part of the ice sheet. Such a stress distribution would be typical of bending deformation, and was also observed to occur by Johnson et al the previous winter at Kadluk. It appears likely that this kind of stress distribution could be caused by thermal stresses. This hypothesis is supported by the output from the CMEL sensor (Figures 46 to 50) which shows a daily cycle of compressive stress which appears to correlate with daily cycling of the air temperature during the period. (The CMEL sensor was in the upper half of the ice sheet).

Bending stresses in the consolidated layer of the grounded rubble might also be induced by tides. An indication of the tidal cycles has been obtained from the piezometers in the island fill. In general the tidal amplitude is less than 0.2 m. Also it occurs twice a day, which does not correlate with the ice stress cycles which are once a day. Thus thermal cycling seems to be the most plausible explanation for the measurements obtained.

13.0 CONCLUSIONS

The ice pressures measured by the sensor at the outside edge of the rubble field were typically up to 200 kPa. Such values are similar to those measured the previous winter during the same period against the same structure (but at a different location) in the Beaufort Sea. The ice pressure events on the south edge of the rubble field appear to correlate best with temperature increases rather than winds. It is speculated that thermal expansion of the landfast ice between the shore and the island is the direct cause of the ice pressure events.

Within the grounded ice rubble, the ice pressures measured indicate that the forces acting on the outside of the rubble are not transmitted through to the structure. This observation is also supported by the negligible ice loads measured by the load cells on the caissons during the same period. A calculation of the typical sliding resistance of the peripheral grounded ice rubble supports this conclusion.

Within the ice rubble, the consolidated layer exhibits a complex stress state through its thickness, typical of bending deformations. It is speculated that these stresses are induced by thermal gradients through the ice thickness.

The results of the surveys of the ice rubble indicate negligible movements of the grounded ice rubble. This supports the speculation that negligible lateral forces were transmitted through it.

Because negligible forces were transmitted through the ice rubble it has not been possible to compare the ice pressures measured by the load cells on the caissons with the ice pressures measured by the in-situ ice pressure sensors placed opposite them. This was one of the objectives of the research program and remains to be addressed by future research projects.

During the conduct of this project, difficulties were experienced with data acquisition system; and also with the equipment used to install the ice panels. These difficulties emphasize once again that careful preparation of equipment to be used in the arctic environment is essential. Despite these difficulties, and the fact that one of the objectives of the project was not achieved because of the extensive grounding of the ice rubble, the study has yielded useful additional information on ice forces and how these forces are transmitted through grounded ice rubble.

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TABLE 1

SENSOR KEY AND LOCATIONS

Location No.	Sensor Type and Serial No.	Distance Along Caisson	Distance Normal To Caisson	Ice Level On Sensor
1	Hexpack (103)	In line with load cell at S. end of caisson 2	5m	On handles
2	Hexpack (104)	8m from N. end of Caisson 4	5m	20cm below handles
3	Ideal	8m from N. end of Caisson 4	8m	46cm to centre of of sensor from ice line
4	CMEL IV-C	9.5m from N. end of caisson 4	5m	30cm below handles
5	Hexpack (105)	In line with 2	27m	30cm below handles
6	Exxon (104)	0.25 caisson length from S. end of Caisson 4	29m	35cm to red line
7	Exxon (103)	not measured	100m	Same As Sensor 6.
	Thermistor Cable	7m from N. end of caisson 4	5m	7-in air 5-0.5m below ice line

TABLE 2

SAMPLE OF EXTRACT FROM ESSO'S DAILY INSTRUMENTATION REPORT

CAISSON RETAINED ISLAND
Instrumentation Report

Location: Amerk 0-09
Author : R Klassen

Date: 16 Mar 1985
Time: 18:22:45

ICE PRESSURES

Microcells			kPa
MI_11	[S/N 02]		+110.9
MI_12	[S/N 03]		+299.3
MI_13	[S/N 04]		+224.8
MI_14	[S/N 05]		+37.6
MI_15	[S/N 07]		+52.6
MI_16	[S/N 08]		-138.0
MI_17	[S/N 09]		-85.7
MI_18	[S/N 10]		+124.8
MI_21	[S/N 13]		+86.7
MI_22	[S/N 14]		+201.4
MI_23	[S/N 15]	*	+15.5
MI_24	[S/N 16]		+212.1
MI_81	[S/N 29]		-2.2
MI_82	[S/N 30]		+928.7
MI_83	[S/N 31]		+445.4
MI_84	[S/N 32]		+266.6

Mcell Replacement		kPa
MR_31a	[S/N 18]	+10.1
MR_41a	[S/N 20]	-23.0
MR_42a	[S/N 21]	+53.9
MR_51a	[S/N 22]	+119.7
MR_52a	[S/N 23]	+7.4
MR_61a	[S/N 24]	-58.2
MR_62a	[S/N 25]	+46.8
MR_71a	[S/N 26]	+40.4

Shearbars			kPa
SB_11	[S/N 01]		-12.8
SB_12	[S/N 06]		-9.5
SB_13	[S/N 11]	*	-13.2
SB_21	[S/N 12]		+5.2
SB_22	[S/N 17]		+54.3
SB_31	[S/N 19]	*	-.1
SB_71	[S/N 27]		+61.4
SB_81	[S/N 28]		+26.9
SB_82	[S/N 33]		-40.8

Comments:
Time of readings is 16 Mar 1985 18:20:00
* Defective Sensors

REPORT No. 191

1985 03 16

ICE CONDITIONS:

There have been no visible changes in the ice or rubble conditions during the past 24 hours. All of the open water areas reported over the past several days are now covered by a thin layer of ice; there is no longer any open water within sight of the CRI.

ICE FORCE SENSORS:

There has been no significant ice force sensor activity during the past 24 hours.

TABLE 3

READINGS OF ICE PRESSURE FROM THE CAISSON LOAD CELLS

		Load Cell No. & Pressure Reading (kPa)				
Date	Day No.	SB 22 NE Caisson	MR 41a SE - N	MR 42a SE - S	MR 51a S - E	MR 52a S - W
Mar 1		74.0	- 9.3	70.8	80.4	52.3
2		82.2	-14.1	67.4	79.2	58.5
3		81.9	-15.0	64.9	78.9	46.6
4		66.5	-15.0	63.1	78.6	39.8
5		65.0	-15.9	61.5	77.7	11.3
6		62.6	-16.2	104.0	71.6	-44.3
7		63.5	-16.5	121.9	72.2	2.1
8		63.4	-17.7	92.9	71.3	4.5
9		64.4	-17.4	88.3	71.0	6.2
10		66.1	-17.4	132.9	70.0	8.9
11		65.4	-18.5	70.8	67.1	9.5
12		65.4	-20.6	89.6	114.5	11.3
13		66.3	-21.2	75.4	120.9	9.2
14		65.7	-23.3	89.9	121.5	8.6
15		54.5	-23.0	57.5	125.5	8.9
16		54.3	-23.0	53.9	119.7	7.4
17		54.4	-20.9	56.0	120.9	4.2
18		51.6	-20.0	64.3	125.2	3.3
19		51.3	-18.8	60.0	123.0	4.8
20	1	42.4	-20.3	57.2	128.5	5.0
21	2	40.6	-19.4	59.1	132.2	- 1.8
22	3	40.6	-17.7	58.8	131.6	- 0.3
23	4	40.5	-16.8	60.0	130.7	- 3.0
24	5	42.6	-16.2	60.0	129.7	- 2.7
25	6	43.3	-16.2	60.3	130.0	0.3
26	7	45.4	-15.6	63.1	130.3	- 0.9
27	8	48.4	-15.9	63.4	130.7	- 0.9
28	9	48.0	-16.2	62.8	131.3	- 0.3
29	10	49.6	-16.8	62.2	130.7	- 0.9
30	11	56.2	-17.4	61.2	131.0	- 0.3
31	12	54.9	-18.8	60.9	129.4	+ 1.2
April 1	13	54.5	-20.9	-27.7	4.6	- 5.9
2	14	34.9	-21.8	-27.4	4.3	0.3
3	15	-5.3	-23.3	-27.7	4.0	4.5
4	16	17.7	-23.3	-28.3	4.6	2.7
5	17	18.9	-21.8	-28.0	4.6	5.0
6	18	20.2	-22.4	-27.7	4.3	6.8
7	19	26.0	-22.1	-28.0	4.6	8.3
8	20	30.5	-20.9	-29.2	6.7	9.2
9	21	32.7	-18.0	-28.9	5.8	8.9
10	22	28.1	-15.6	-28.0	5.5	8.6
11	23	30.9	-17.1	-27.7	5.2	7.7
12	24	27.6	-18.2	-28.0	5.2	7.7
13	25	29.4	-19.7	-28.6	5.5	11.6
						Cont'd

Table 3 cont'd

		Load Cell No. & Pressure Reading (kPa)				
Date	Day No.	SB 22 NE Caisson	MR 41a SE - N	MR 42a SE - S	MR 51a S - E	MR 52a S - W
14	26	23.6	-20.0	-28.0	5.2	19.9
15	29	20.7	-21.2	-28.0	4.9	24.6
16	28	26.5	-21.8	-28.6	5.2	23.5
17	29	27.0	-22.7	-28.3	4.9	28.8
18	30	22.6	-22.4	-28.3	4.6	15.1
19	31	27.3	-20.9	-28.3	5.5	10.7
20	32	27.7	-19.1	-28.3	5.5	1.2
21	33	30.8	-20.6	-28.0	5.5	-1.8
22	34	38.2	-21.5	-27.7	4.9	0.6
23	35	31.2	-25.1	-27.7	4.6	0.9
24	36	20.1	-29.6	-28.3	5.2	1.8
25	37	11.0	-32.9	-28.9	4.6	5.9
26	38	9.6	-32.9	-30.2	4.6	1.8
27	39	-254.8	-32.3	-29.2	4.0	-5.3
28	40	-354.5	-31.7	-29.5	4.6	-5.9
29	41	-319.0	-32.6	-29.9	3.4	-6.5
30	42	-216.4	-33.5	43.5	120.6	2.7
May 1	43	-66.2	-36.2	44.3	120.0	-6.5
2	44	+70.0	-39.2	42.2	120.9	0.3
3	45	74.5	-42.8	39.7	99.9	6.5
4	46	84.9	-42.8	38.5	99.6	2.1
5	47	88.5	-39.5	40.0	98.1	-6.2
6	48	49.0	-55.6	39.7	50.6	-3.9
7	49	24.8	-55.3	38.8	64.3	-6.2
8	50	27.1	-49.1	35.4	65.8	-2.4
9	51	38.4	-47.3	14.2	65.8	-7.1
10	52	85.8	-51.2	27.7	64.3	-5.9
11	53	133.9	-51.2	27.4	64.0	-4.5
12	54					
13	55	131.7	-42.2	23.4	63.0	-0.3

TABLE 4

METEOROLOGICAL DATA FOR THE MONITORING PERIOD

Day	Date	Wind Speed kph	Wind Direction °True	Air Temperature High °C	Air Temperature Low °C	Barometric Pressure kPa	Overhead Conditions
1	March 20	25 - 30	230 - 280	-20.7	-24.2	101.6	Clearing
2	21	20 decreasing to 5	250 - 270	-18.4	-29.8	101.8	Clear
3	22	25 decreasing to 45	65 - 80	-17.0	-25.9	101.7	Clear
4	23	35 - 40	65 - 70	-18.3	-22.2	101.6	Clear
5	24	45 - 50	75 - 85	-18.8	-24.1	101.6	Clear
6	25	45 - 55	85 - 95	-18.4	-23.6	102.1	Clear
7	26	10 - 15	220	-16.6	-26.4	102.5	Clear
8	27	15 increasing to 25	280 - 300	-19.9	-25.8	102.2	Clear
9	28	20 decreasing to 5	270 veering 160	-16.6	-28.5	101.8	Clear
10	29	5 - 15	135	-19.2	-25.6	101.3	Light Overcast
11	30	10 increasing to 35	330 - 335	-21.4	-26.0	101.2	Clear
12	31	5 - 10	320 - 330	-17.4	-24.9	101.1	Scattered Cloud
13	April 1	5 increasing to 25	330 - 300	-15.6	-21.7	101.6	Cloudy - Snow
14	2	calm	-	-12.5	-18.8	101.4	Cloudy - Snow
15	3	5 - 10	90 veering to 190	-14.7	-22.6	101.7	Clearing
16	4	10 - 20	80 - 100	-17.2		102.4	Clear
17	5	20 decreasing to 5	80	-16.4	-25.2	102.4	Clear
18	6	5 - 15	230 - 260	-18.9	-27.3	103.0	Clear
19	7	5 - 15	300 veering to 80	-17.5	-29.7	103.1	Clear
20	8	50 - 60	50 - 60	-19.7	-23.3	102.2	Clear
21	9	50 decreasing to 20	45 - 50	-20.9	-25.4	102.4	Clear
22	10	5 - 10	330 - 30	-19.1	-27.6	103.1	Clear
23	11	5 - 10	270 - 300	-18.0	-27.9	102.4	Clear
24	12	5 increasing to 30	40 - 80	-18.0	-27.1	102.4	Clear
25	13	40	50 - 60	-17.8	-21.9	102.1	Clear
26	14	50 decreasing to 10	50 veering to 90	-14.0	-21.0	102.3	Clear
27	15	20 - 30	80 - 90	-15.6	-22.7	101.8	Clear
28	16	30 - 40	70	-13.8	-22.7	100.6	Clear
29	17	20 - 30	40 - 60	-18.8	-22.1	100.2	Clear
30	18	20	320 - 350	-19.8	-26.6	101.1	Clear
31	19	20 - 30	40 veering to 90	-17.7	-27.5	102.4	Clear
32	20	20 - 30	20 - 30	-18.0	-27.9	102.0	Clear
33	21	30	50 - 60	-17.0	-22.4	102.2	Scattered Cloud
34	22	20 - 25	80 - 90	-11.4	-21.4	102.0	Cloudy - Snow
35	23	calm		- 7.5		102.0	Clear
36	24	0 - 5	220 - 240	-11.1	-20.8	102.5	Scattered Cloud
37	25	0 - 5	220 veering to 60	- 9.9	-17.4	102.3	Clear
38	26	30 increasing to 50	70 - 75	- 9.7	-15.7	101.8	High Scattered Cloud
39	27	40 decreasing to 20	70 veering to 45	-10.5	-16.1	101.9	Clear
40	28	0 - 5	35 - 45	-10.8	-19.5	101.7	Clear
41	29	0 - 15	90 - 105	- 8.0	-18.3	101.6	Clear
42	30	10 - 20	90 - 95	- 4.9	-17.3	101.4	Clear
43	May 1	0 - 5	65 - 75	- 5.1	-14.1	101.6	Clear
44	2	0 - 5	85 - 95	- 1.4	-14.2	101.5	Clear
45	3	10 - 20	75 - 85	- 0.5	- 9.9	100.8	Overcast to Clearing
46	4	0 - 5	40 - 80	- 3.0	- 8.3	101.7	Cloud

TABLE 5

ICE RUBBLE DISPLACEMENTS - BY SURVEY

Reflector	Coordinates[1] (m) East	Coordinates[1] (m) North	24 Feb. to 13 May Displacement (m)	24 Feb. to 13 May Angle[2] (deg)	13 May to 15 May Displacment (m)	13 May to 15 May Angle[2] (deg)
1	39.678	92.476	0.009	1.9	0.177	-73.9
2	77.500	47.917	0.073	57.8	0.123	-31.7
3	50.858	-56.466	0.009	-58.5	0.008	31.0
4	19.667	-80.235	-	-	0.007	38.8
6	7.303	-55.307	0.147	-8.6	0.009	28.5
7	10.596	-30.155	0.004	-49.5	0.006	54.9
8	24.659	-14.569	-	-	0.009	-83.1

[1] Coordinates relative to the southeast corner of the helideck
[2] Angle clockwise from north

TABLE 6

DESCRIPTIONS OF HOLES DRILLED THROUGH ICE ON MAY 16, 1985

Hole No.	Location	Description
1	Near sensor 5	- Solid to 1m; slightly slushy at 1m - 2.5m; water at 2.5m still resistance below; void at 3.8m; still vertical resistance below.
2	5m towards caisson from 1	- Solid to 1.5m; slushy 1.5 - 2.5m; water at 2.5m but vertical resistance below.
3	Near sensor 7	- Solid to 0.5m then slightly slushy; 2m wet slush; auger stuck at 3m but wet; 4m still in rubble but very wet.
4	Outside rubble on south side, 7m from tidal crack on slightly bulged ice.	- Uniform ice, thickness 1.84m.

THE ESSO CAISSON RETAINED ISLAND

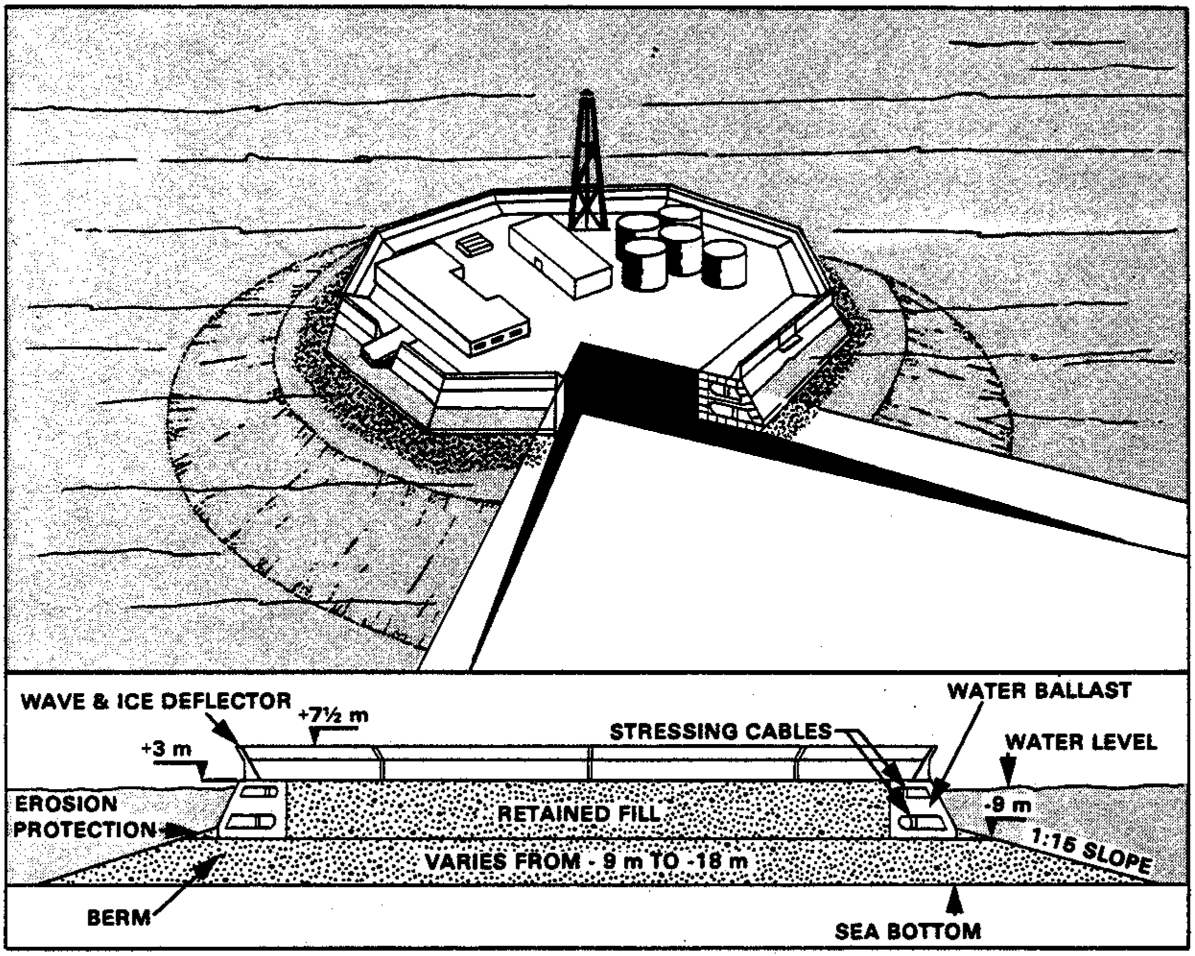


Figure 1

ARTIFICIAL ISLANDS/DRILLING LOCATIONS

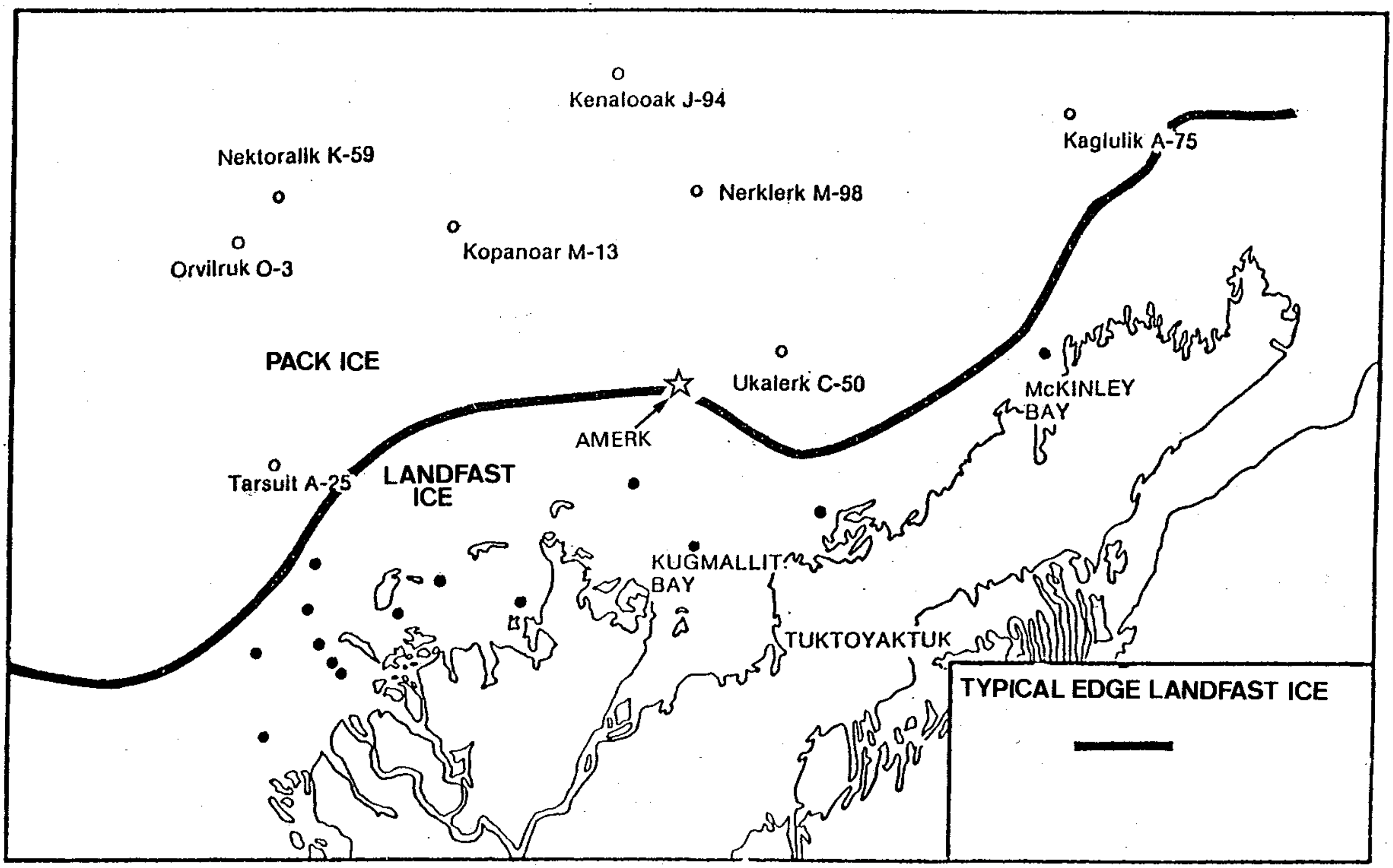
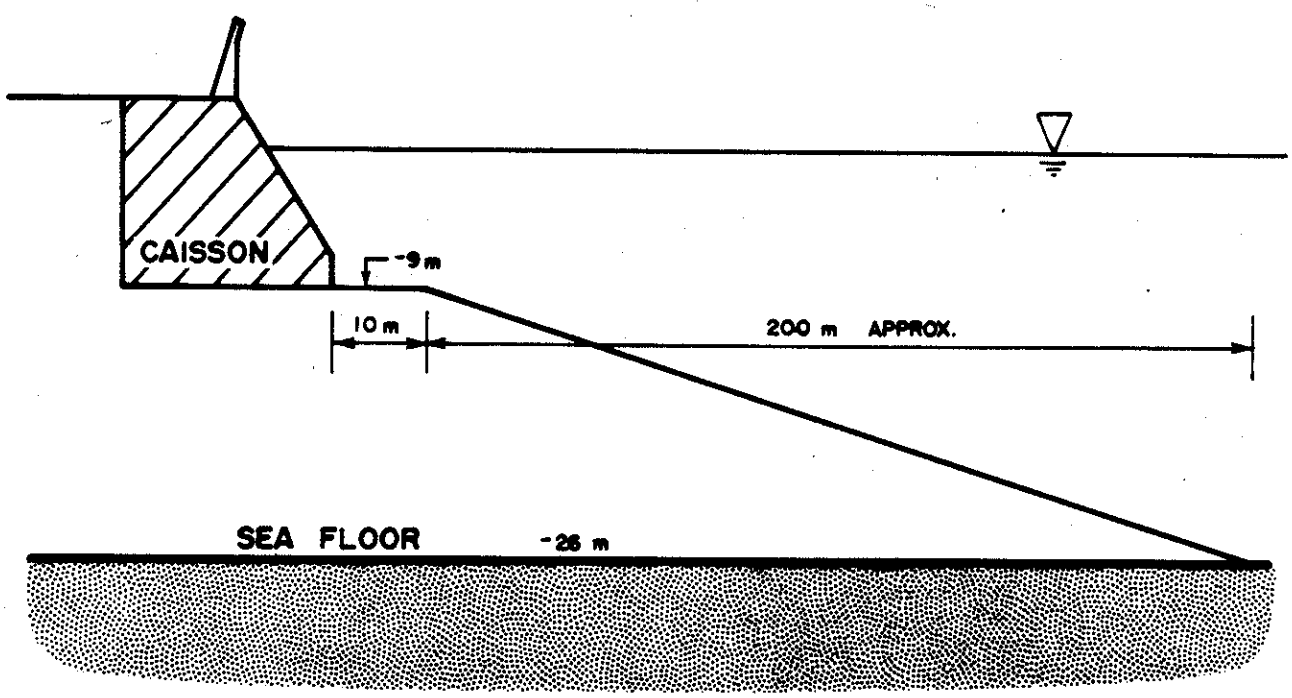
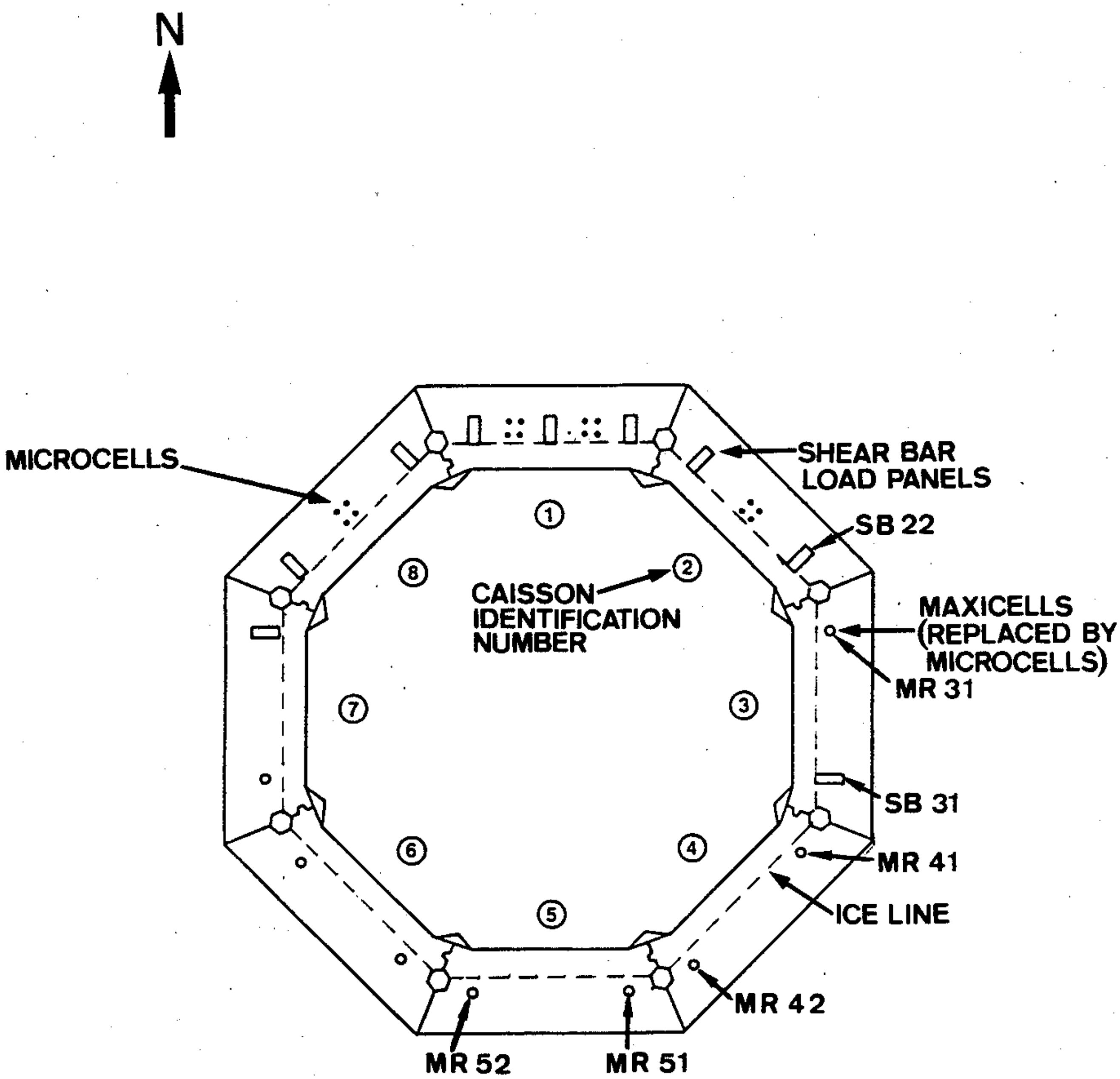


Figure 2



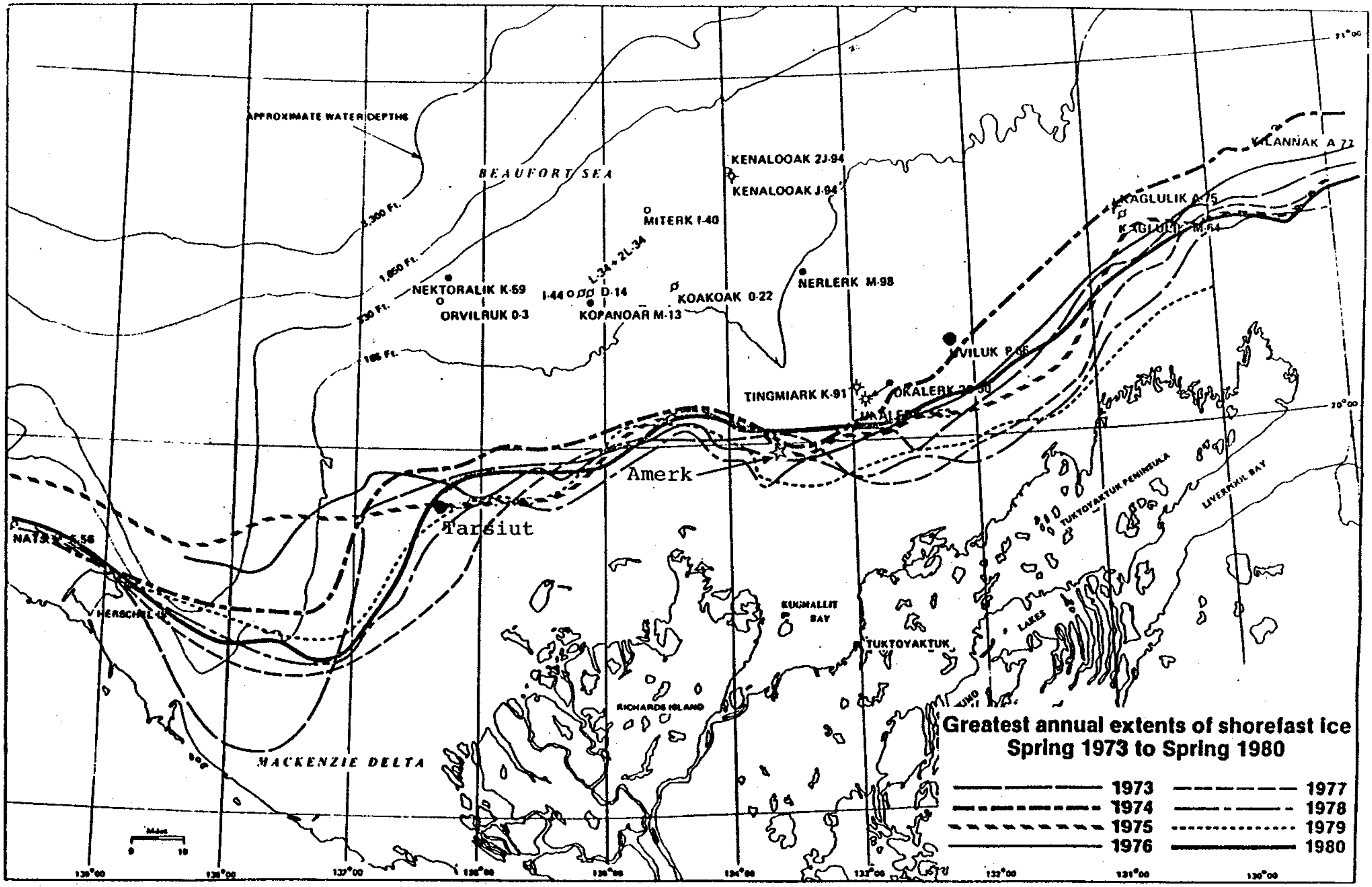
TYPICAL BERM PROFILE AT AMERK

Figure 3



ESSO CRI ICE LOAD SENSORS

Figure 4



Greatest annual extents of shorefast ice
Spring 1973 to Spring 1980
1973
1974
1975
1976
1977
1978
1979
1980
APPROXIMATE WATER DEPTHS
BEAUFORT SEA
3,300 Ft.
1,650 Ft.
330 Ft.
165 Ft.
KENALOOAK 2J-94
KENALOOAK J-94
MITERK I-40
NERLERK M-98
KOAKOAK 0-22
KOPANOAR M-13
D-14
I-44
L-34 + 2L-34
NEKTORALIK K-59
ORVILRUK 0-3
TINGMIARK K-91
OKALERK
KAGLULIK A-75
KAGLULIK M-64
Amerk
Tarsiut
HERSCHEL
MACKENZIE DELTA
RICHARDS ISLAND
KUGMALLIT BAY
TUKTOYAKTUK
TUKTOYAKTUK PENINSULA
LIVERPOOL BAY
LAKES
Miles
0
10
139°00
138°00
137°00
136°00
135°00
134°00
133°00
132°00
131°00
130°00
70°00
71°00

Figure 5

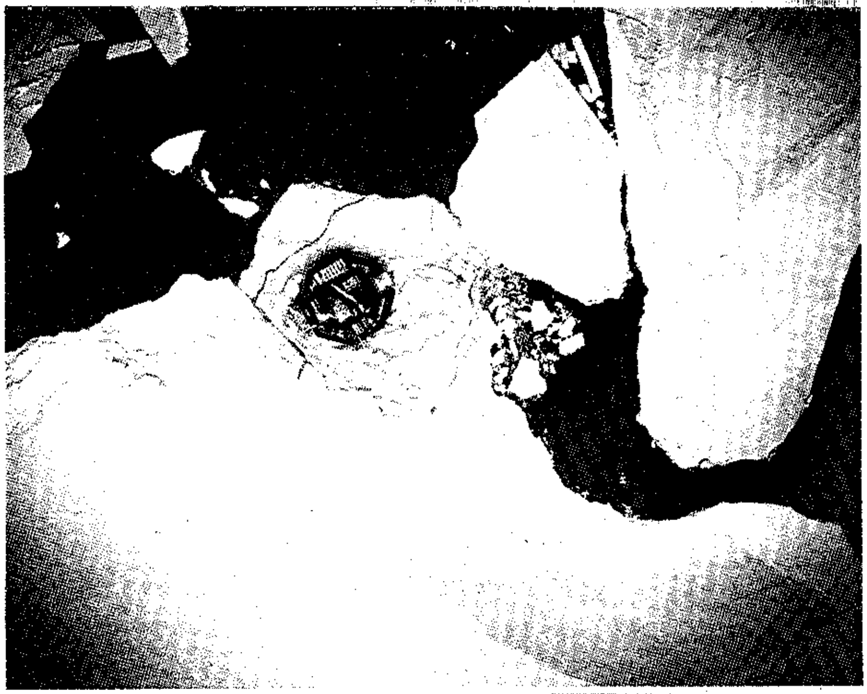


Figure 6
(November 1984)

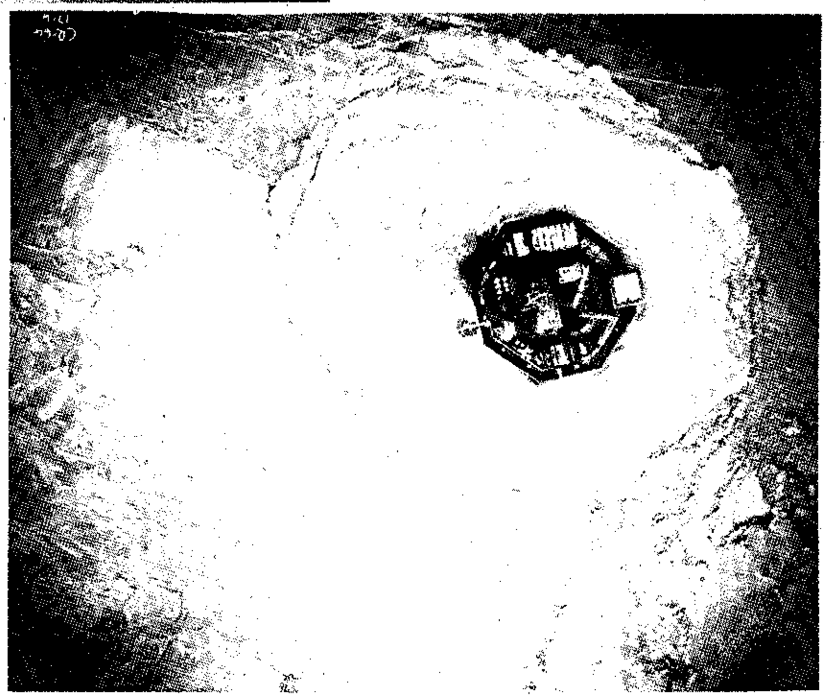


Figure 7
(January 1985)

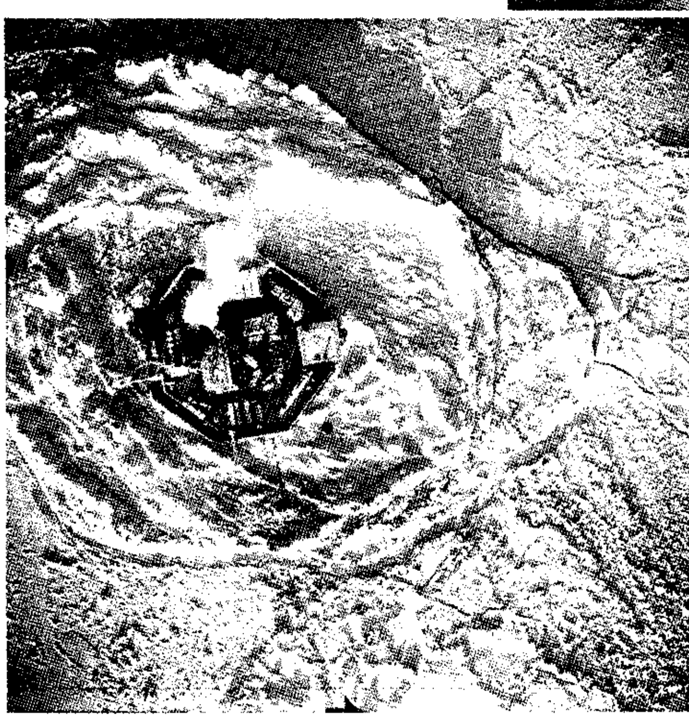


Figure 8
(Feb. 1985)

AERIAL PHOTO'S OF ICE RUBBLE

ICE AND RUBBLE CONDITIONS
AMERK O-09 85/01/30

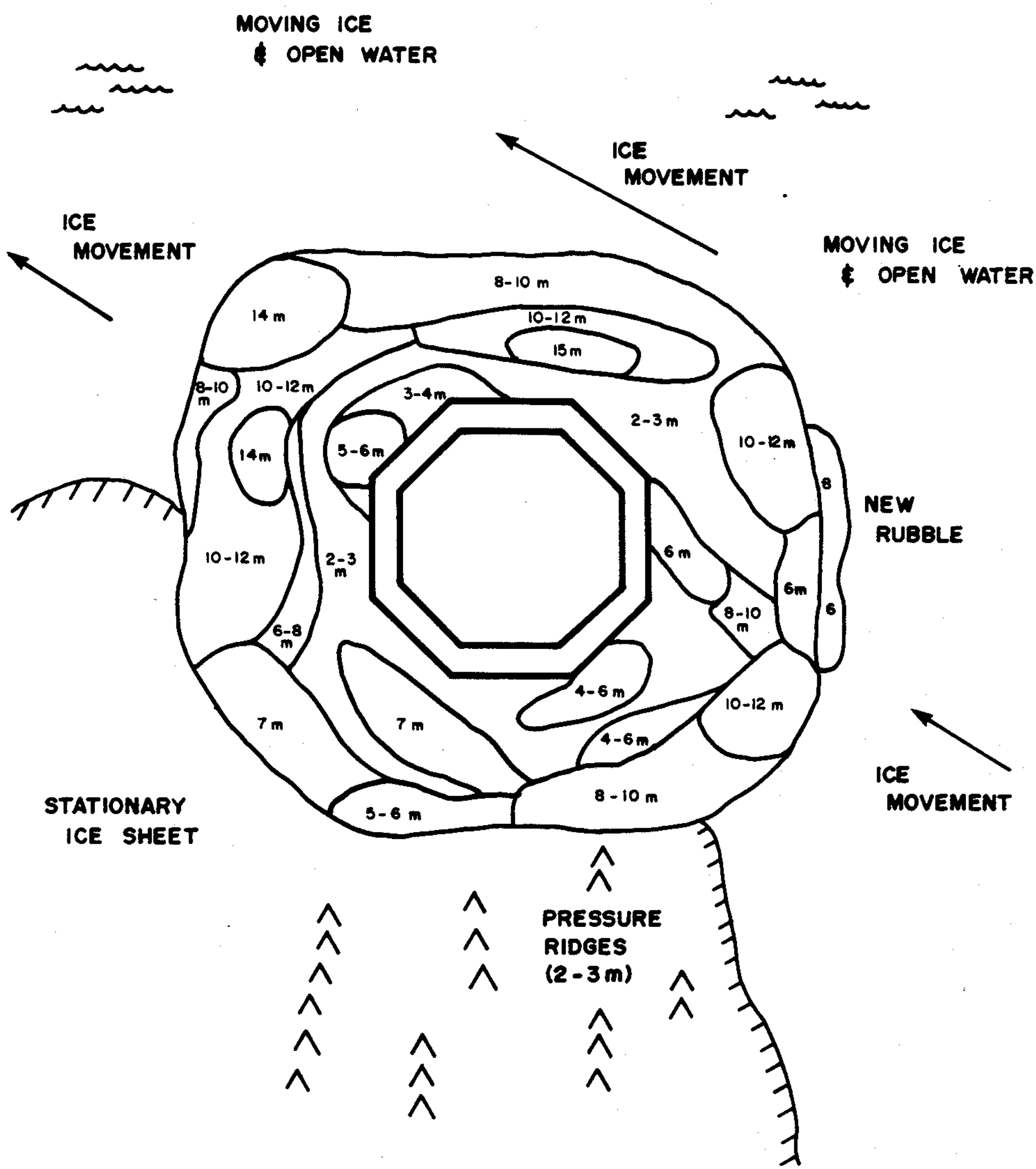
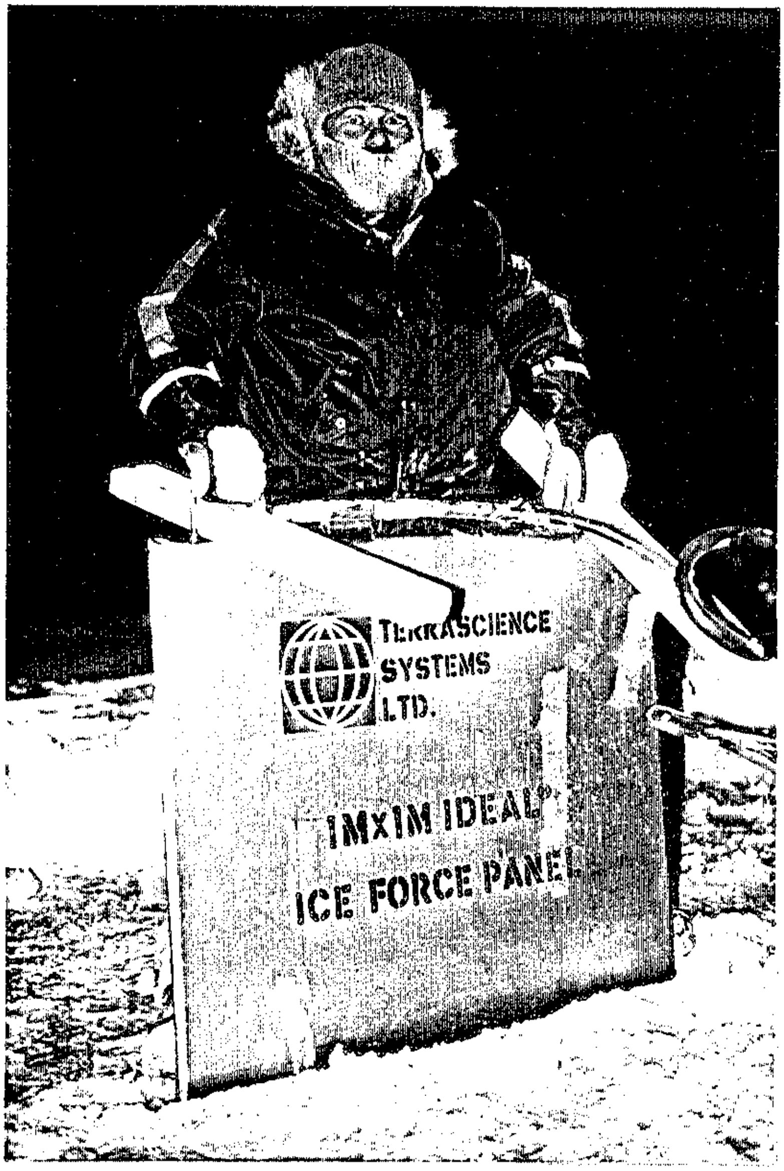
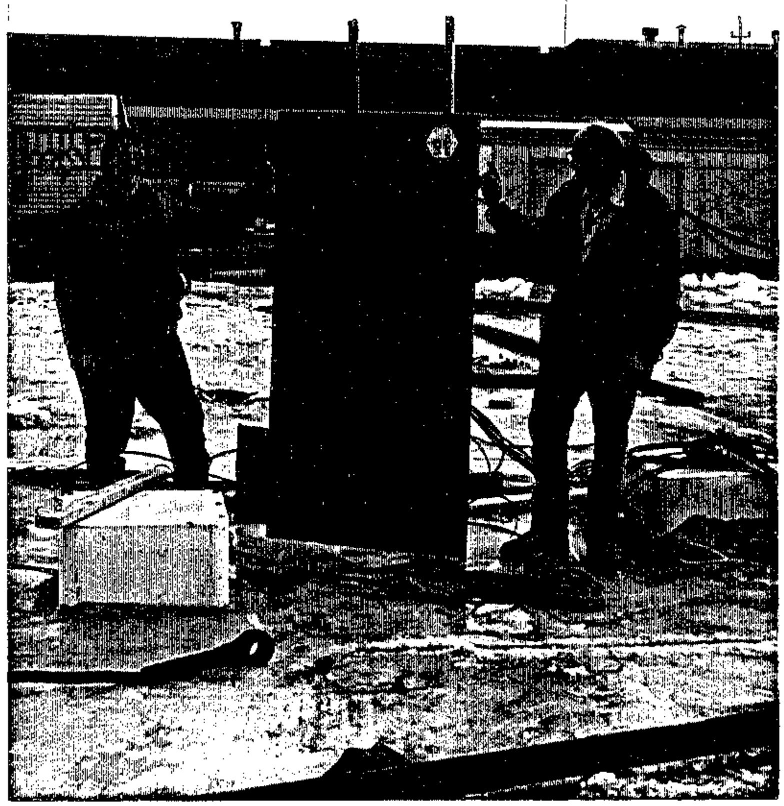


Figure 9



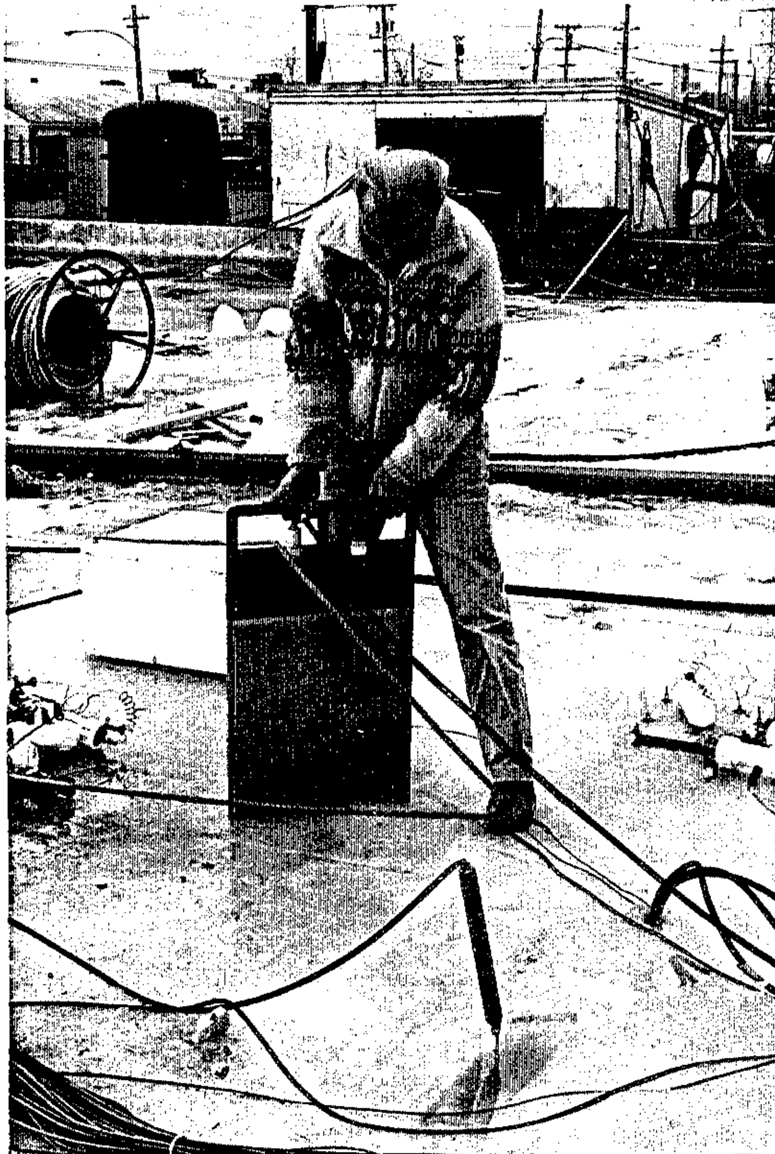
IDEAL 1m X 1m PANEL

Figure 10



ARCTEC 2m HEXPACK

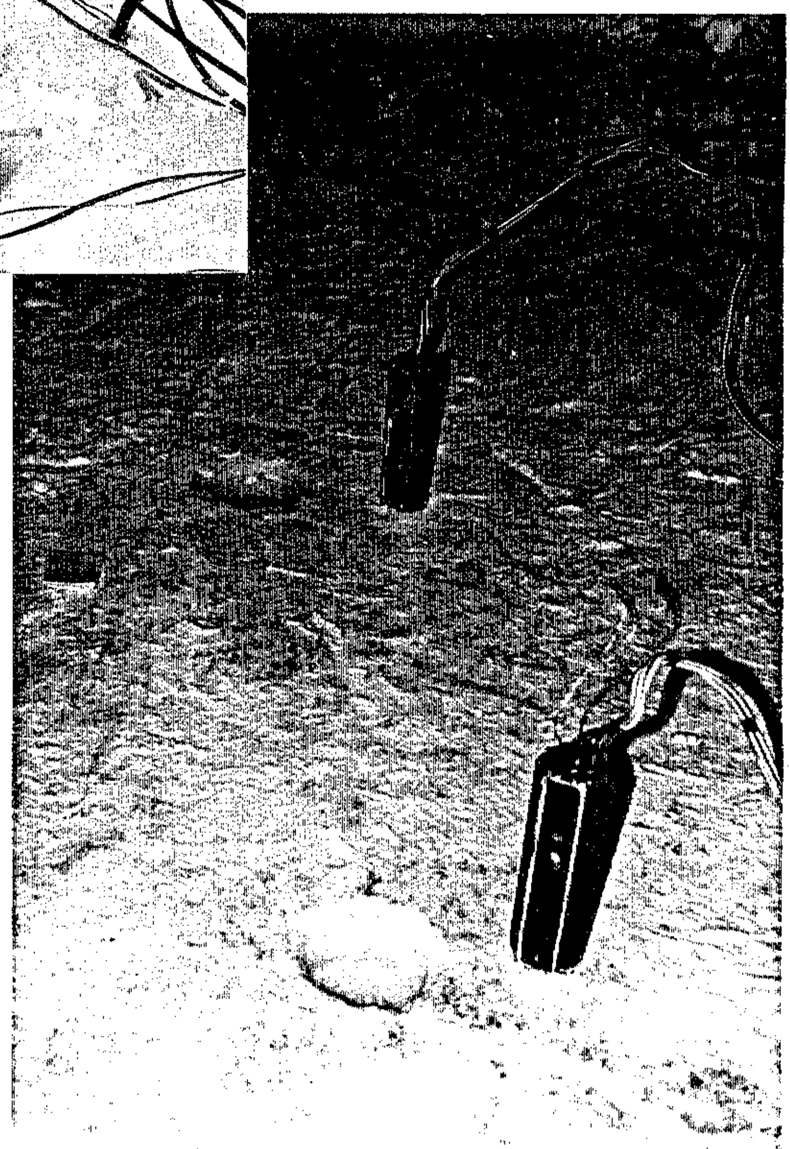
Figure 11



EXXON (ESSO)

2m PANEL (IN ICE)

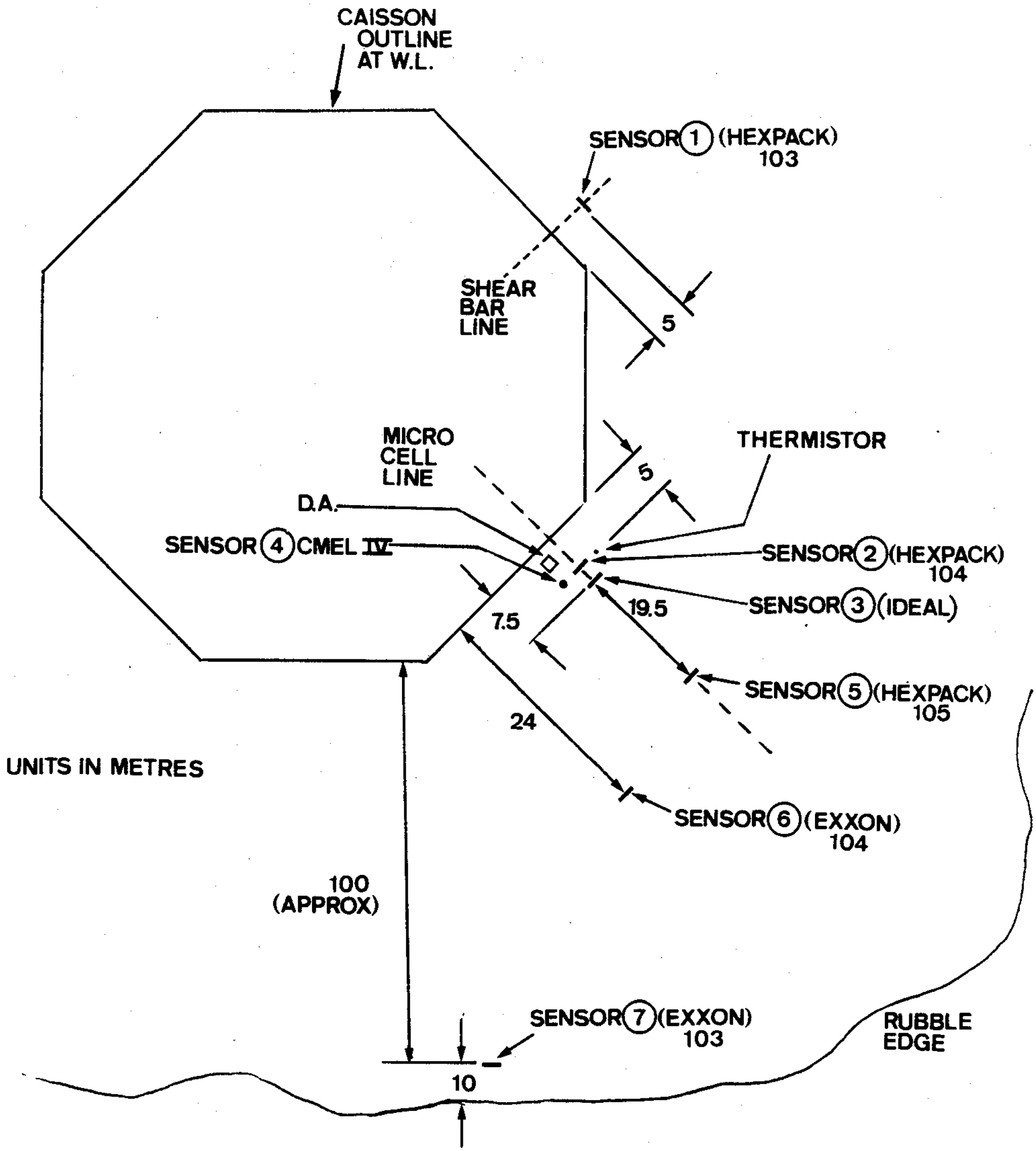
Figure 12



C.M.E.L. MARK IV-C

BIAXIAL SENSOR

Figure 13



SENSOR LOCATION AND IDENTIFICATION NUMBERS

Figure 14

SENSOR INSTALLATION

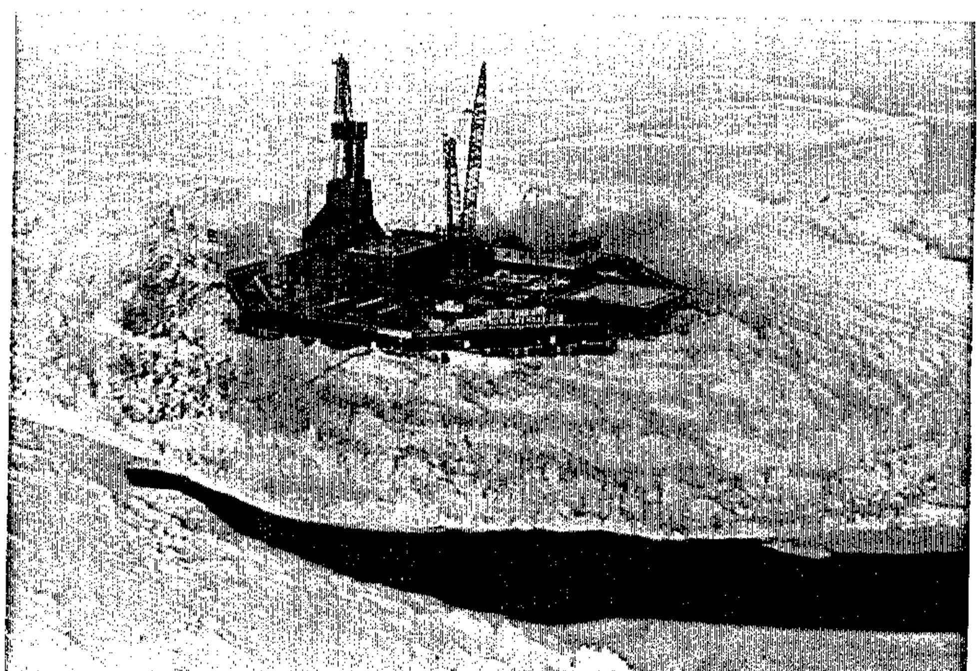
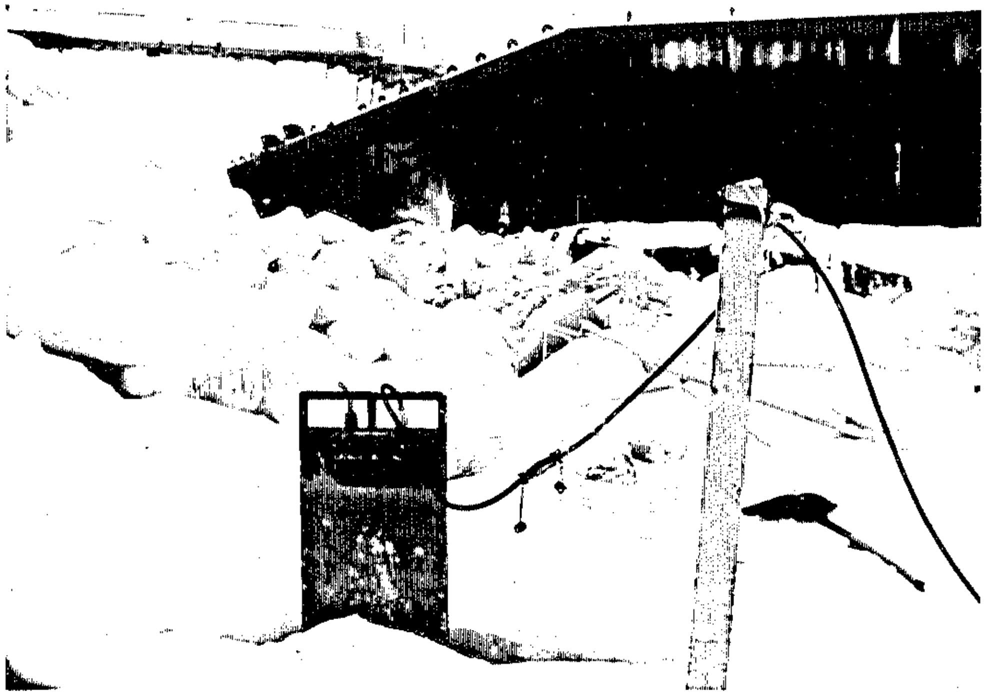
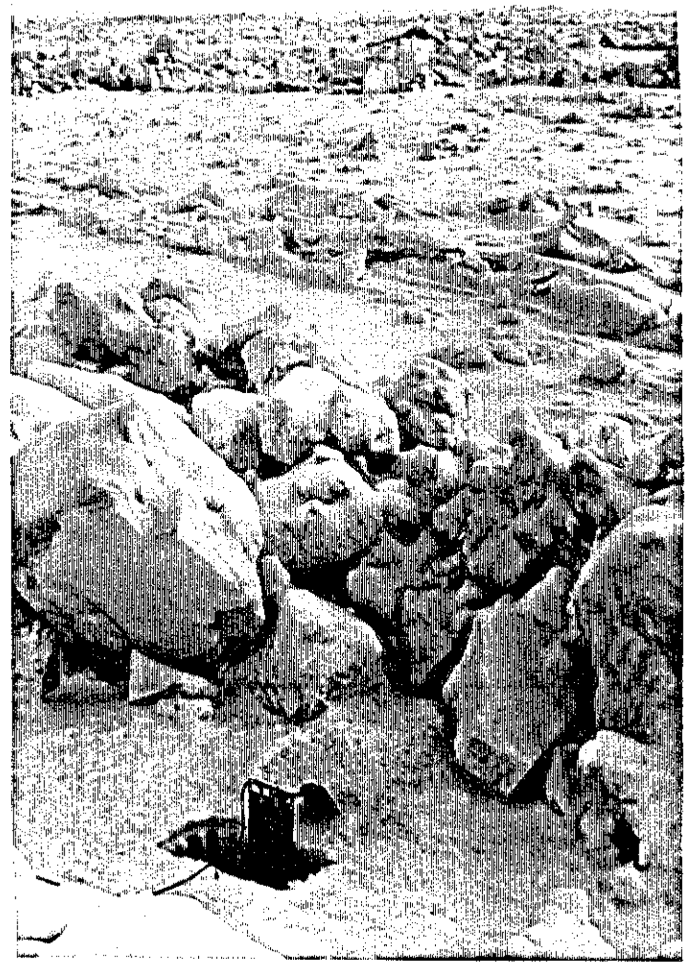


Figure 15



Sensor 6



Sensor 7

Sensors 2,3&4

SENSOR INSTALLATION

Figure 16

Figure 17

SENSOR REMOVAL USING STEAM WAND.

Figure 18

SENSOR 7 (EXXON 103) JUST PRIOR TO REMOVAL

Figure 19

* ESSO S PANEL 103

* Note all references to Esso panels in these figures are to Exxon panels supplied by Esso.

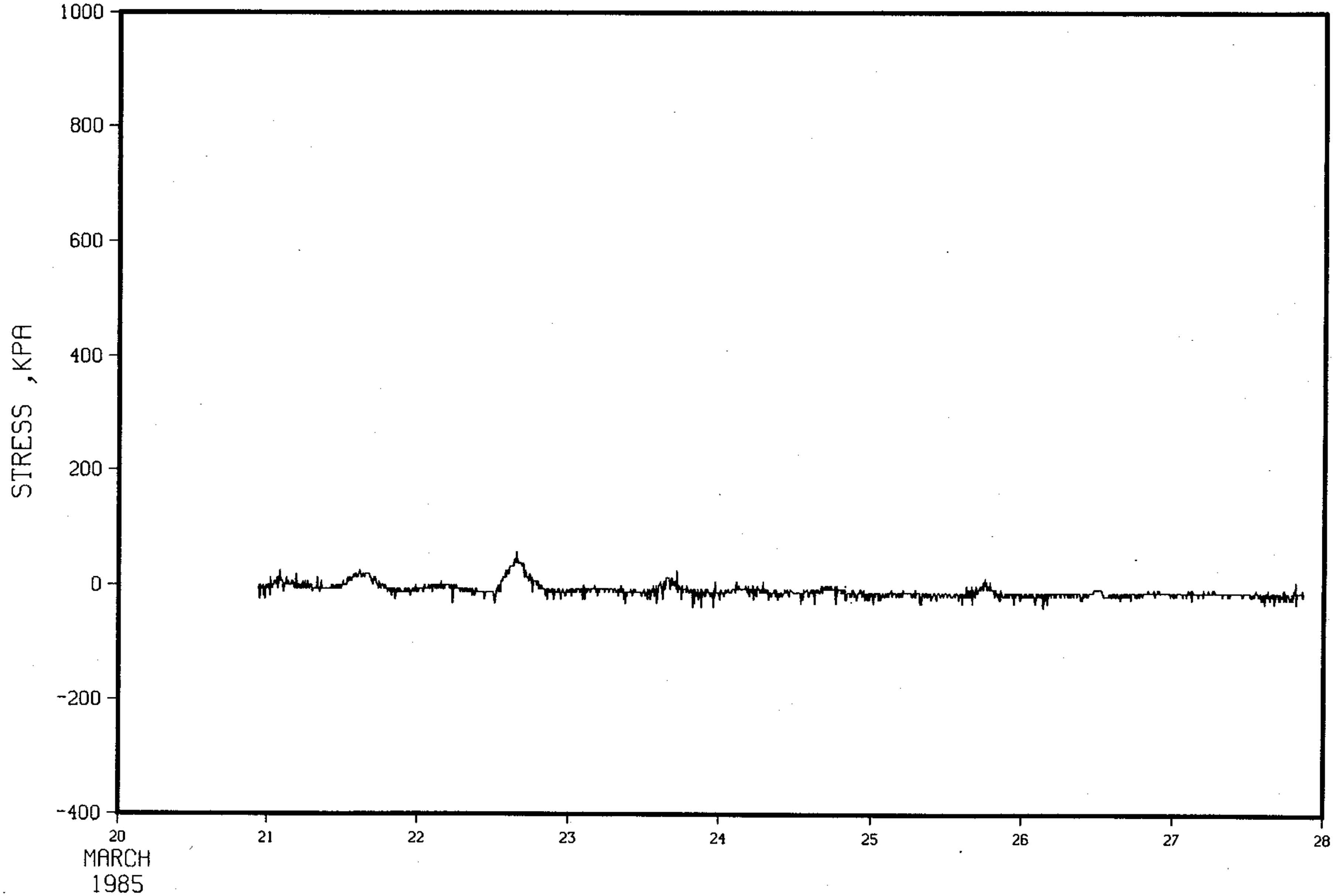
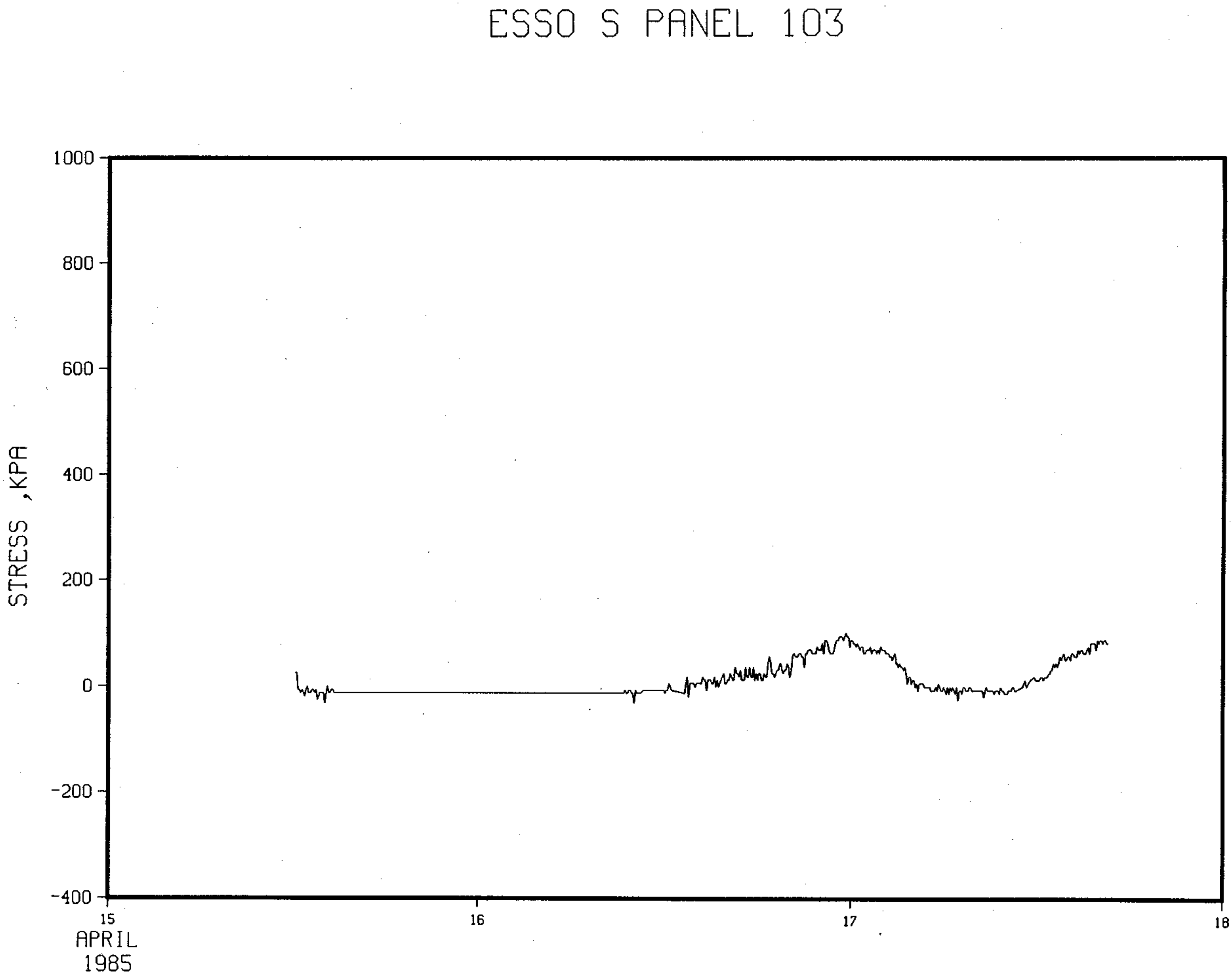


Figure 20



ESSO S PANEL 103
STRESS ,KPA
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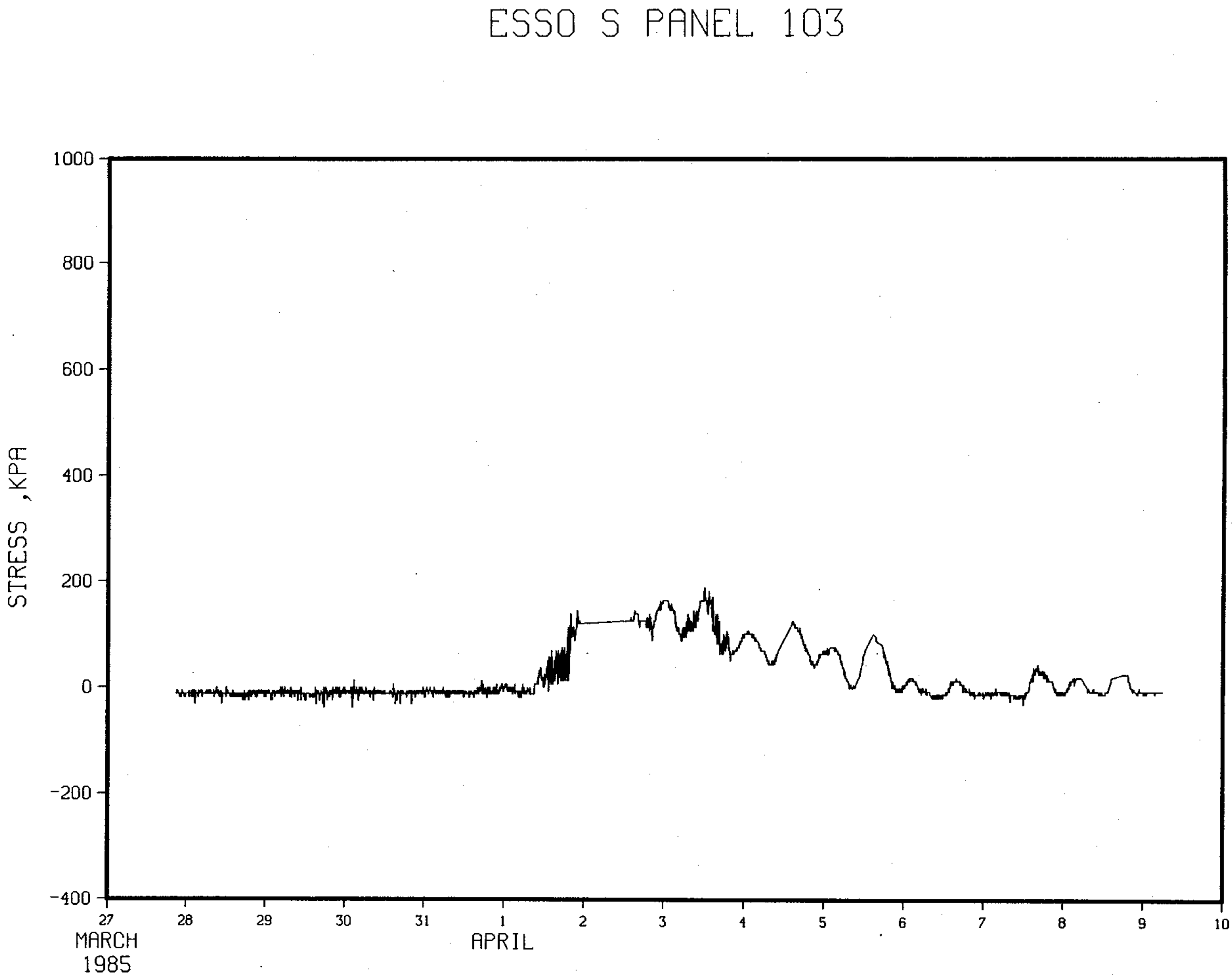
Figure 21



ESSO S PANEL 103
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Figure 22

ESSO S PANEL 103

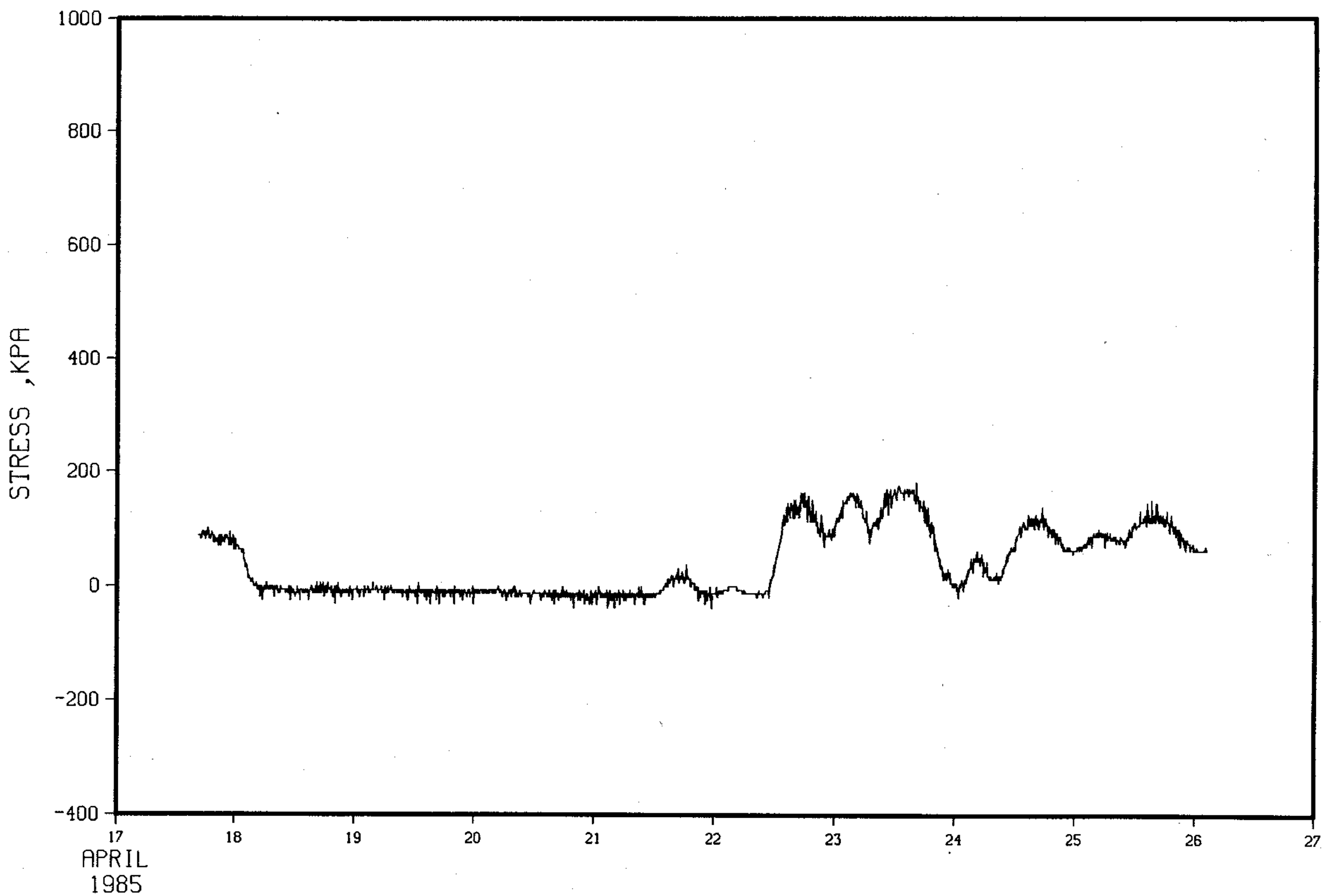


Figure 23

ESSO S PANEL 103

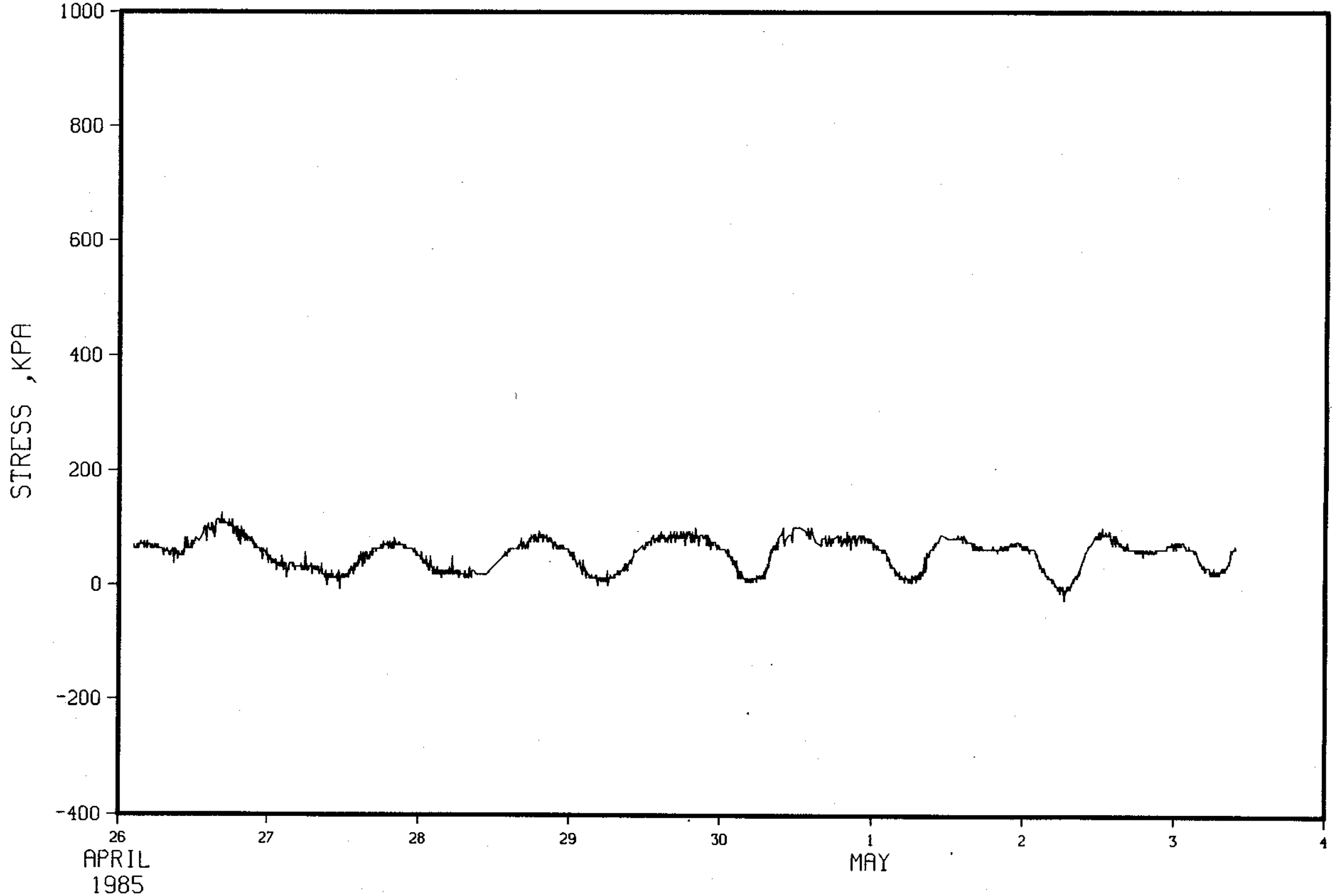


Figure 24

ESSO S PANEL 104

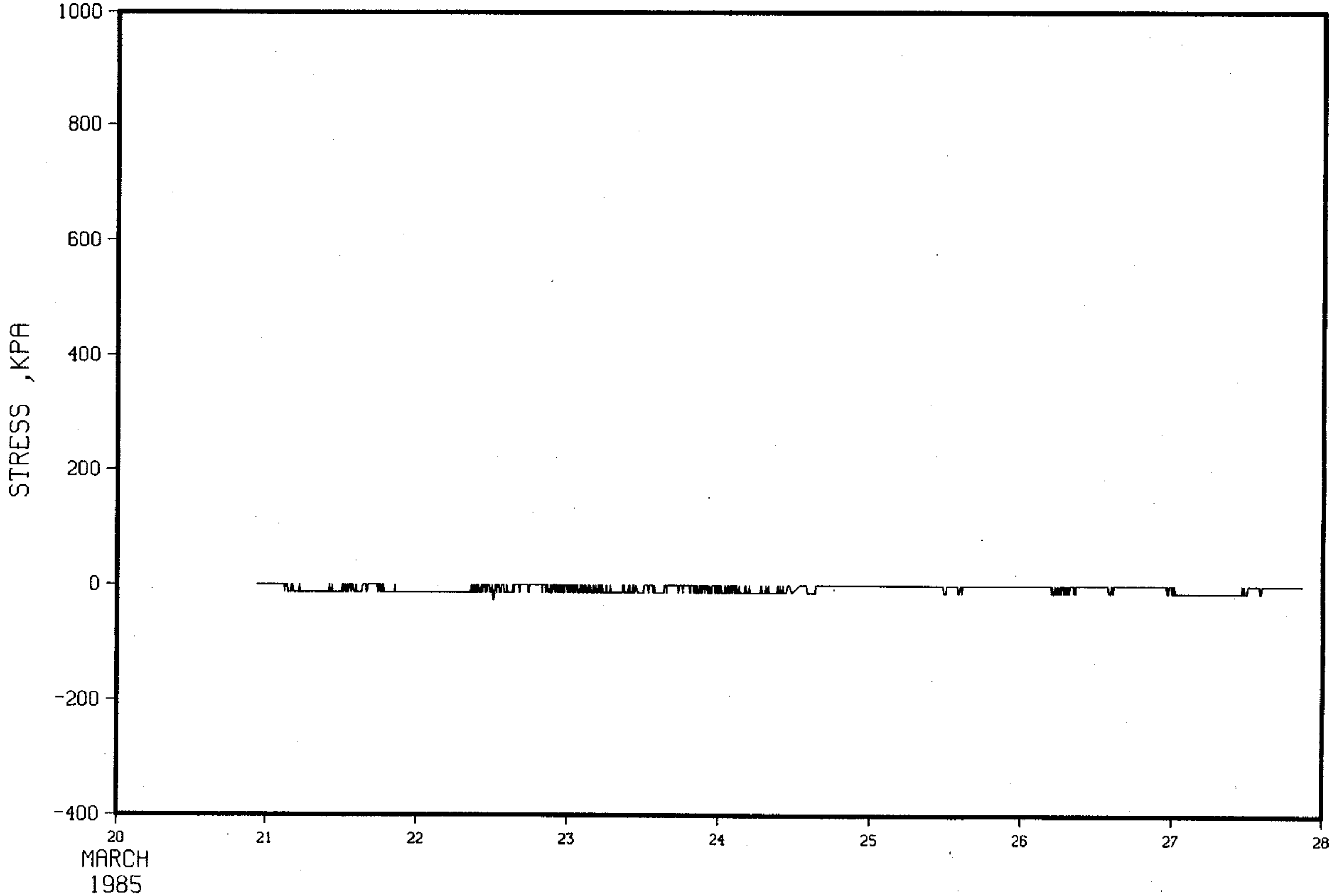
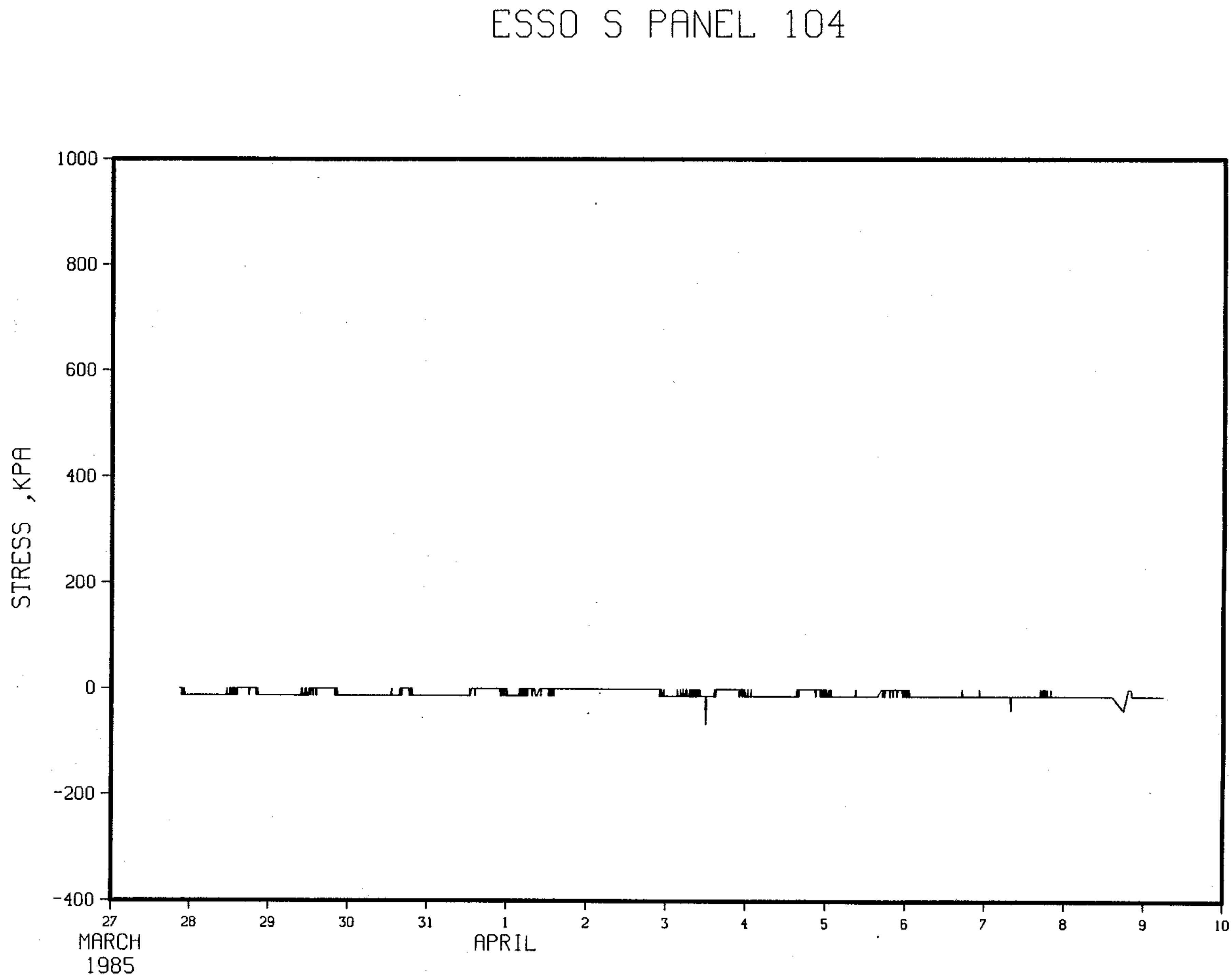


Figure 25



ESSO S PANEL 104
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Figure 26

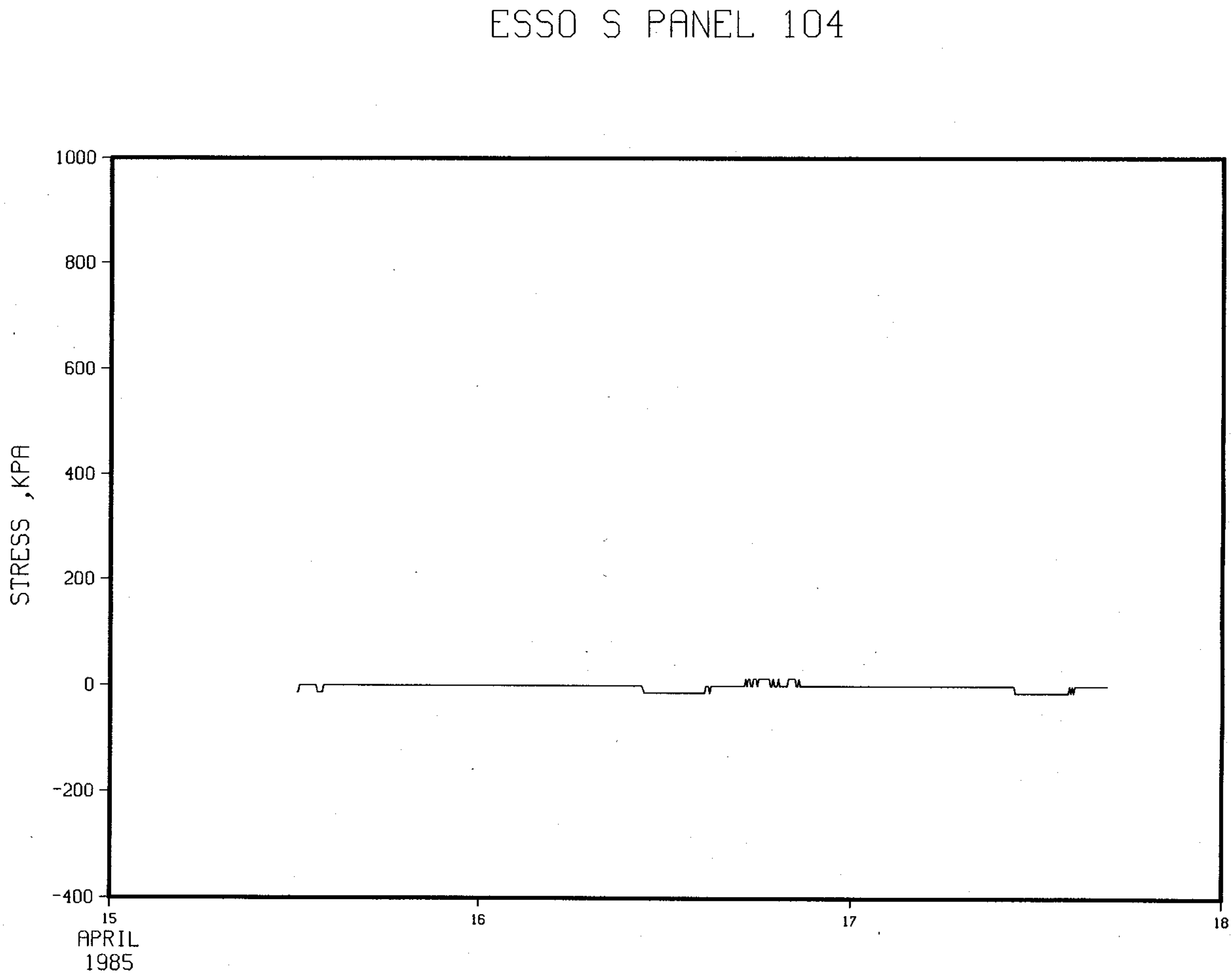
ESSO S PANEL 104
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Figure 27

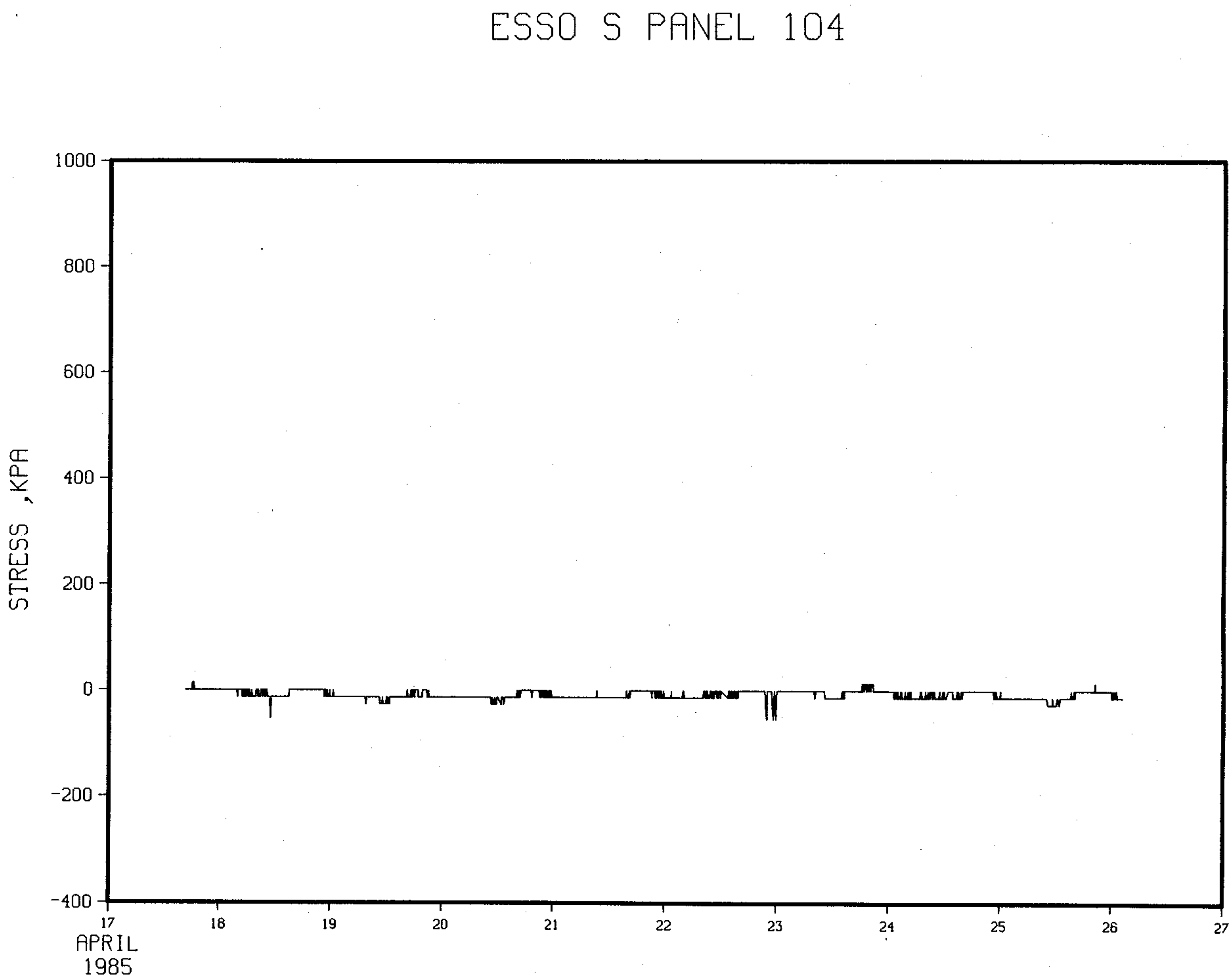
ESSO S PANEL 104
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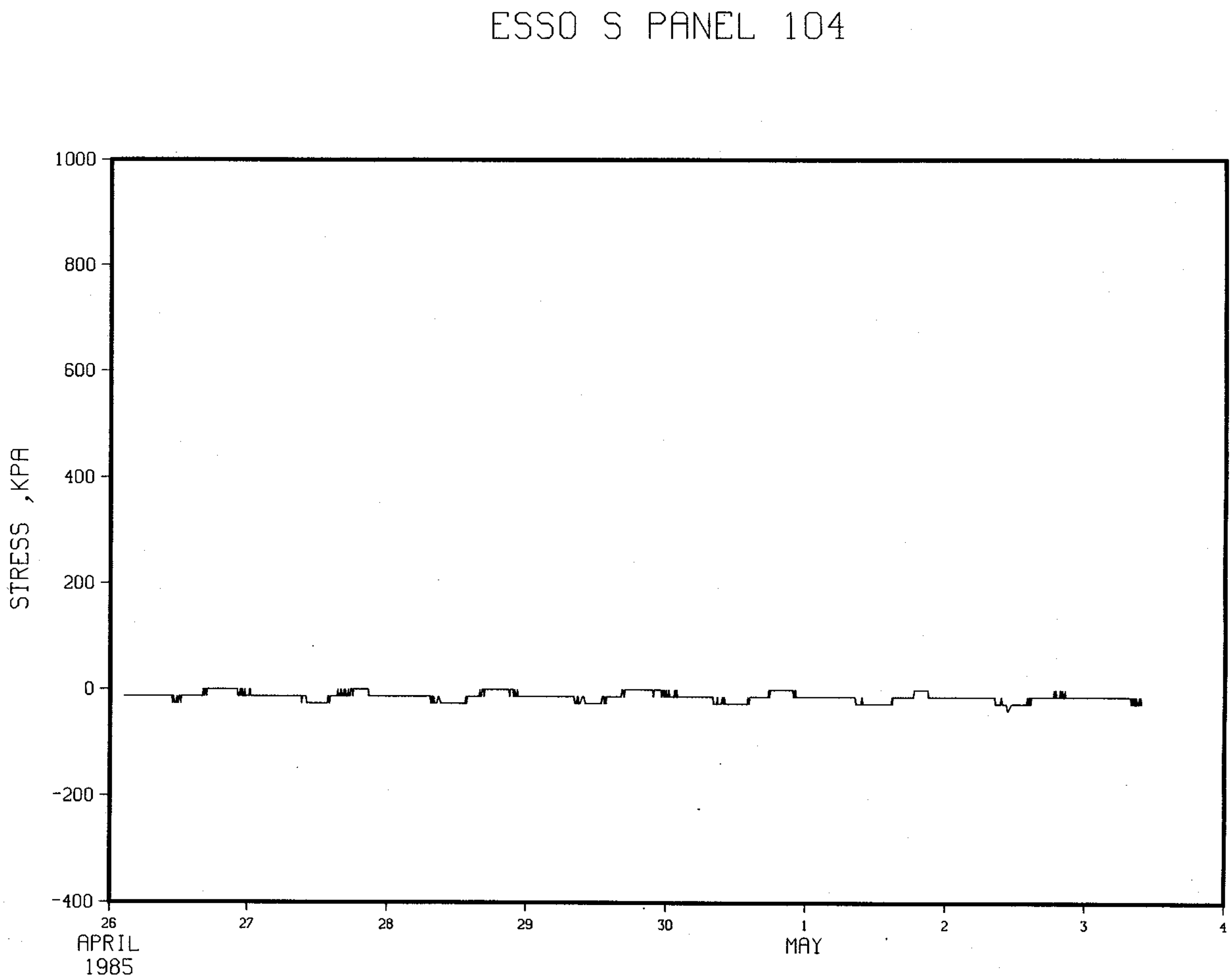
Figure 28


ESSO S PANEL 104
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APRIL
1985
MAY

Figure 29

HEX PANEL 103

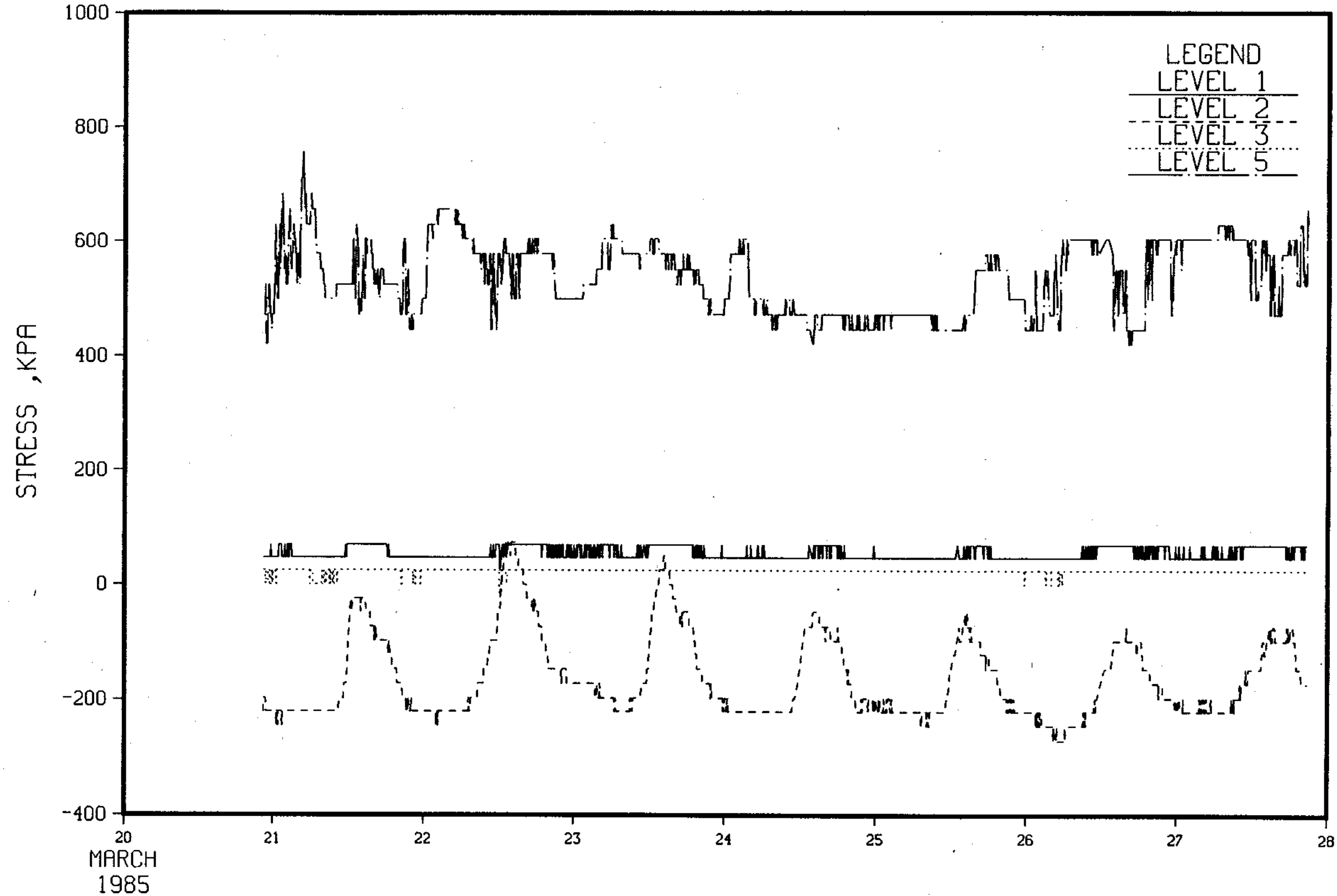
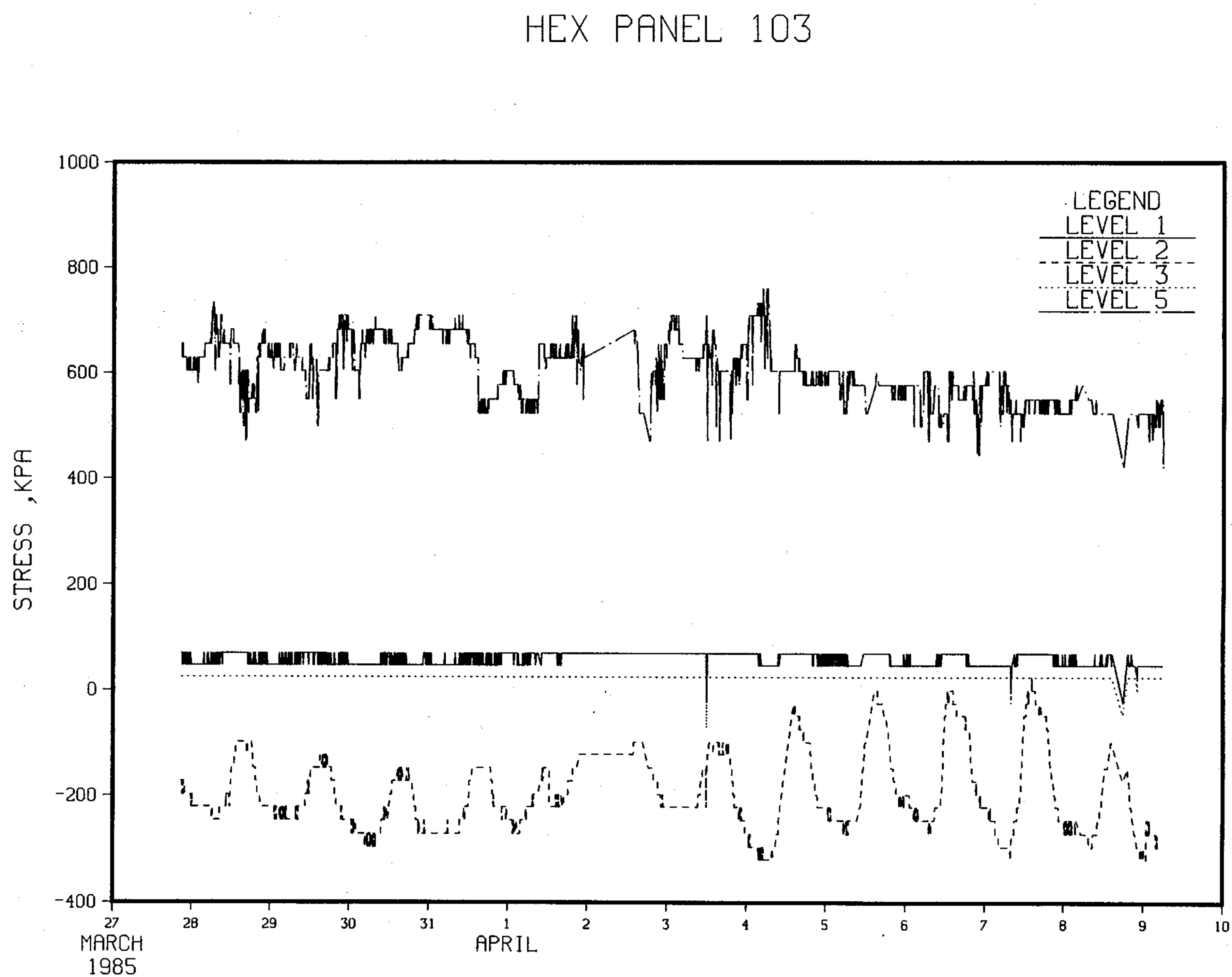


Figure 30



HEX PANEL 103
LEGEND
LEVEL 1
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LEVEL 3
LEVEL 5
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MARCH
1985
APRIL

Figure 31

HEX PANEL 103

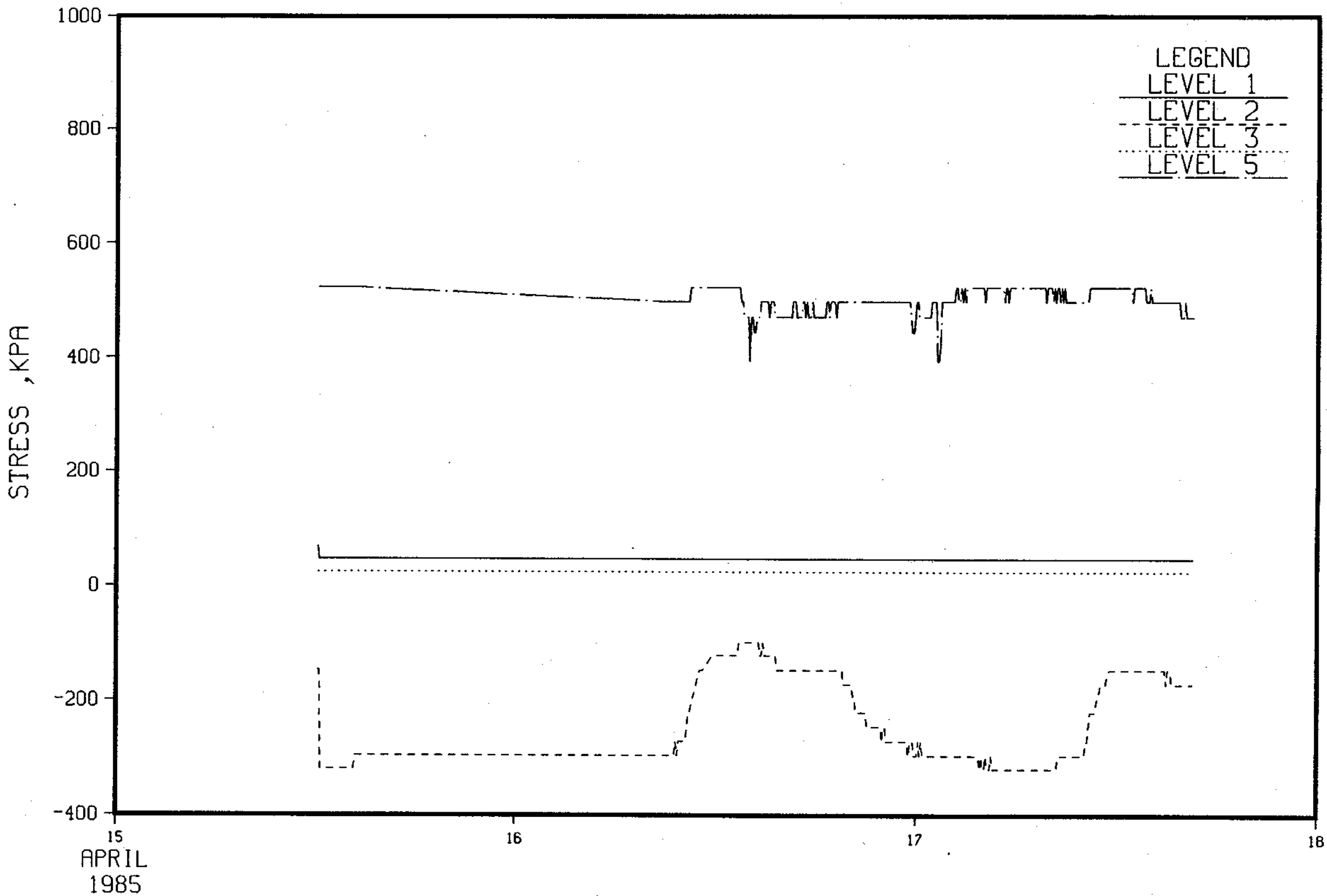


Figure 32

HEX PANEL 103

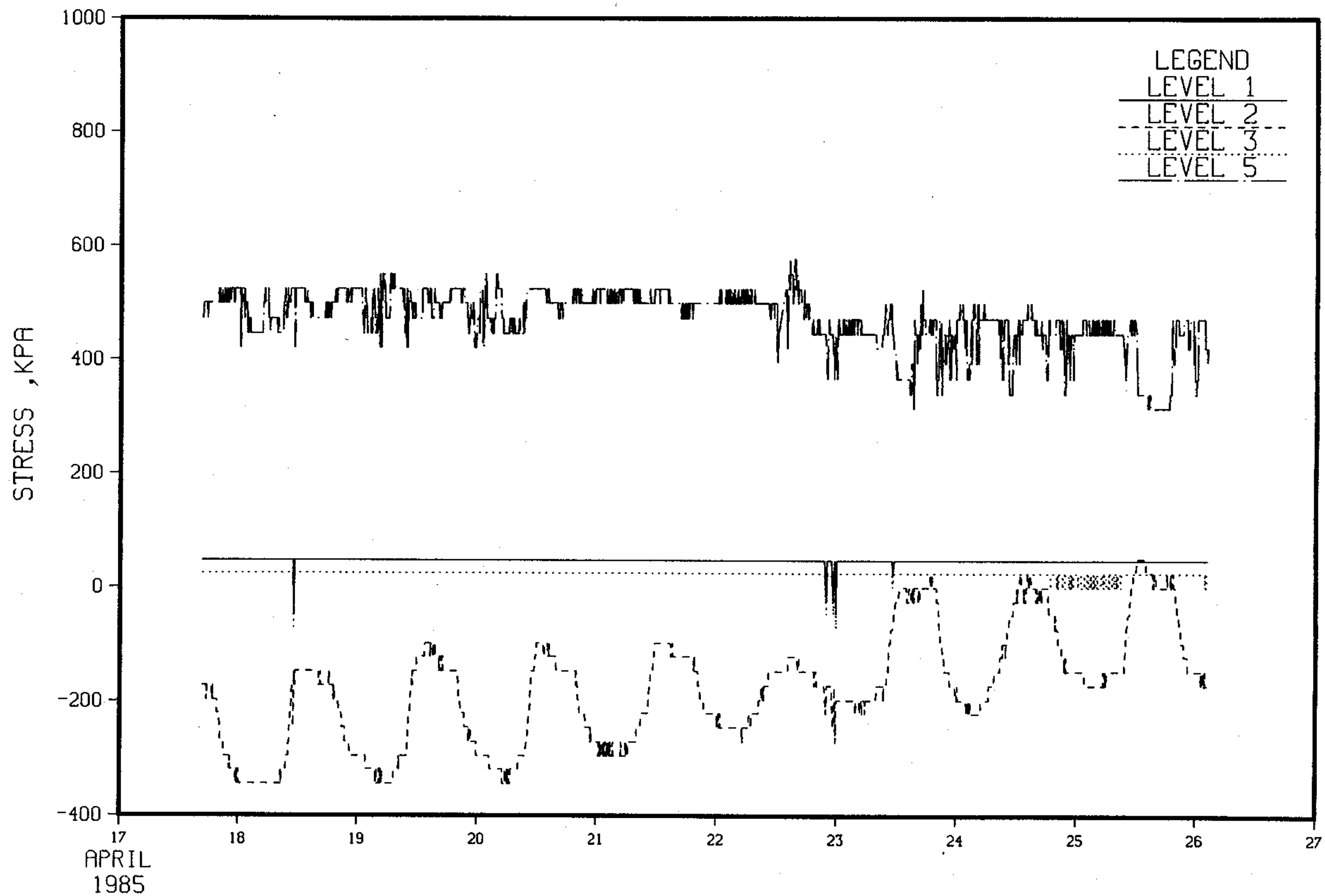


Figure 33

HEX PANEL 103

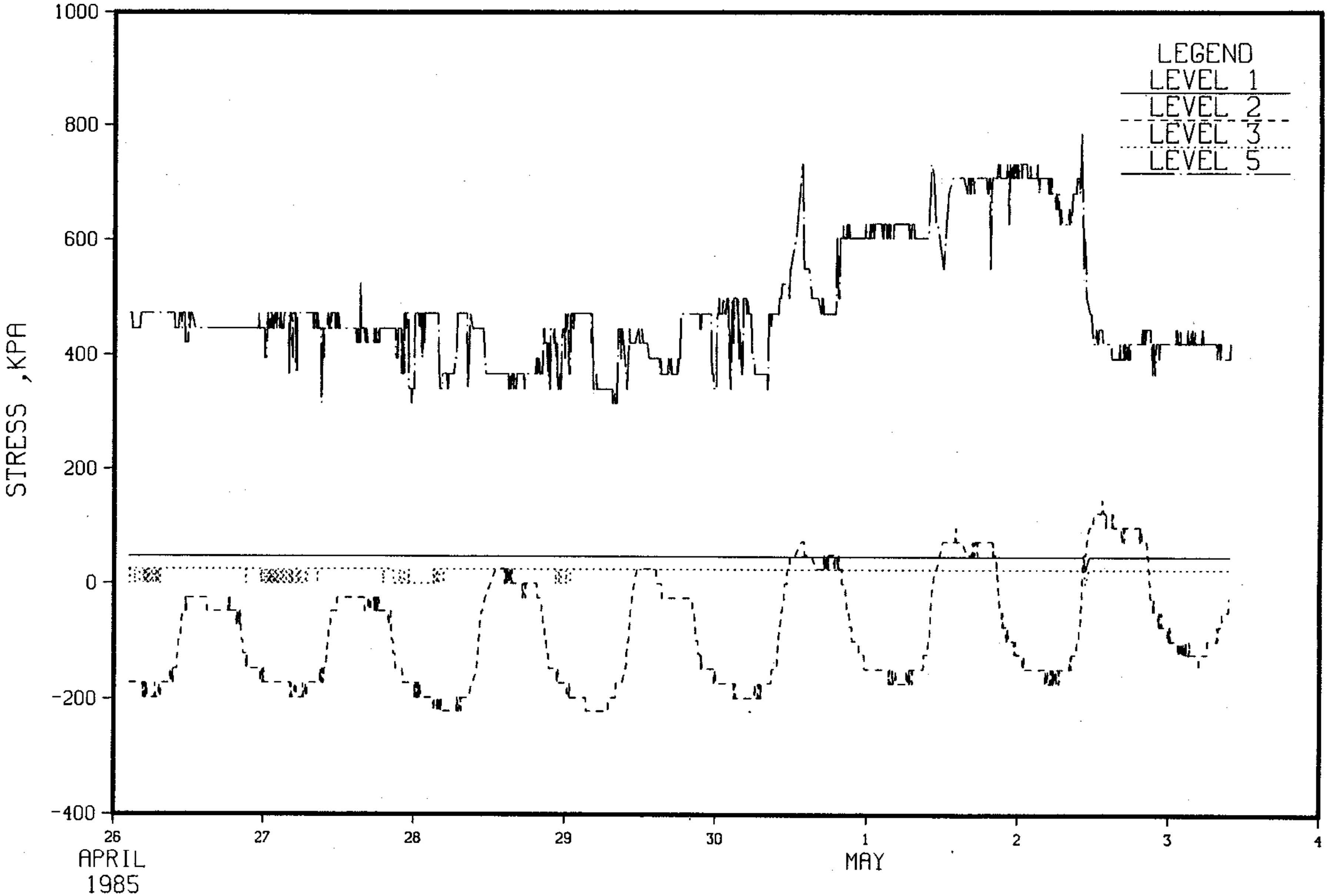
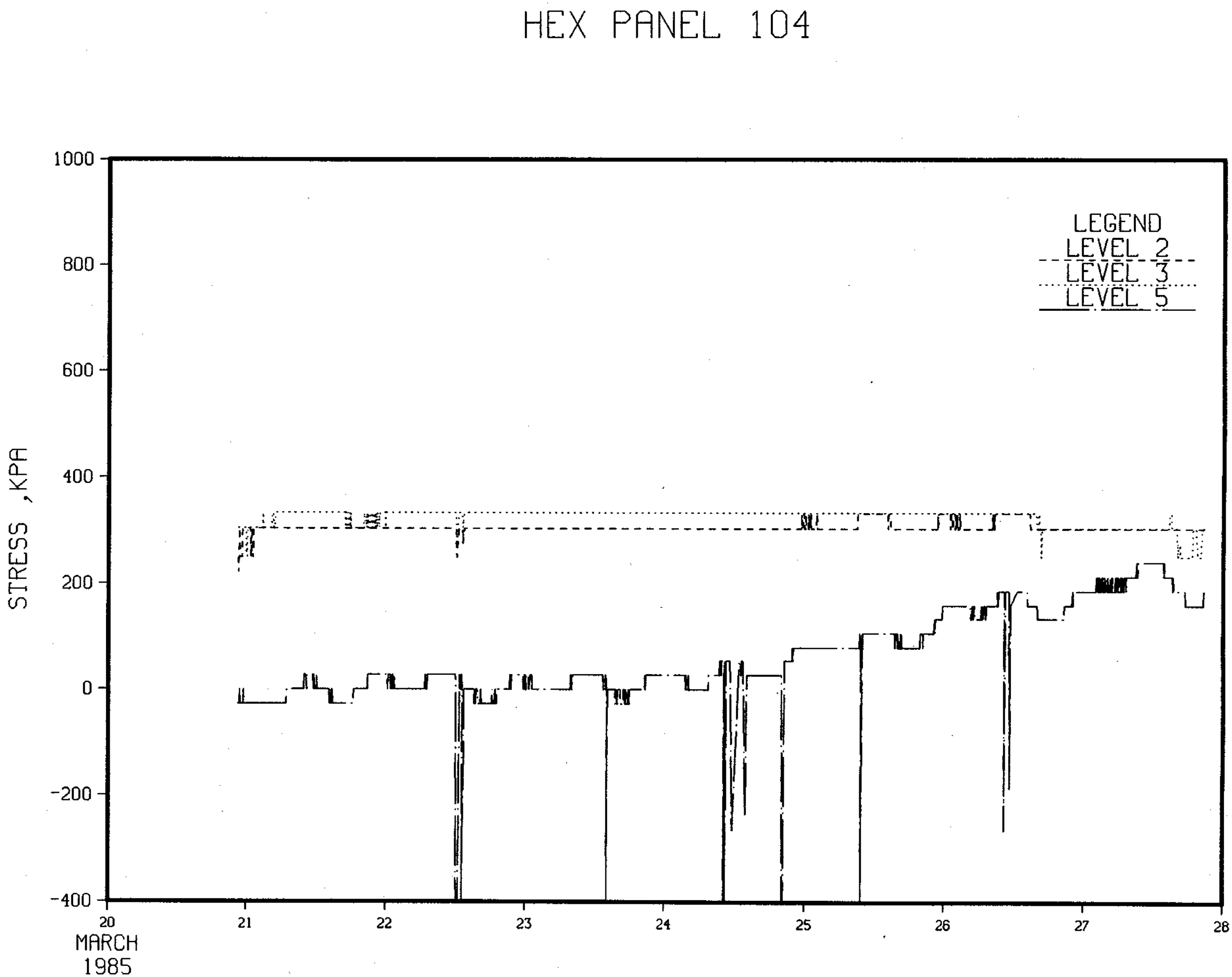


Figure 34



HEX PANEL 104
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MARCH
1985

Figure 35

HEX PANEL 104

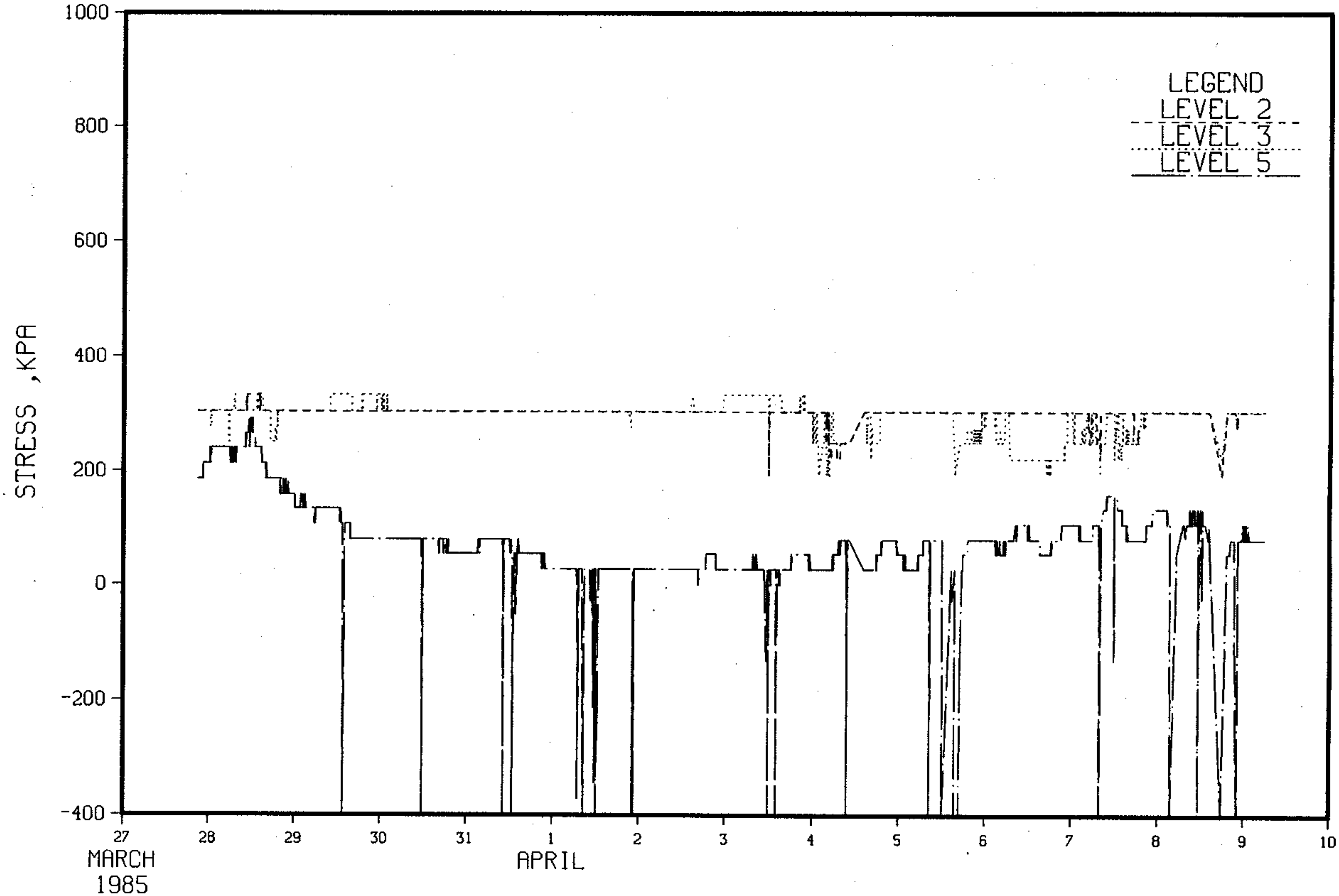


Figure 36

HEX PANEL 104

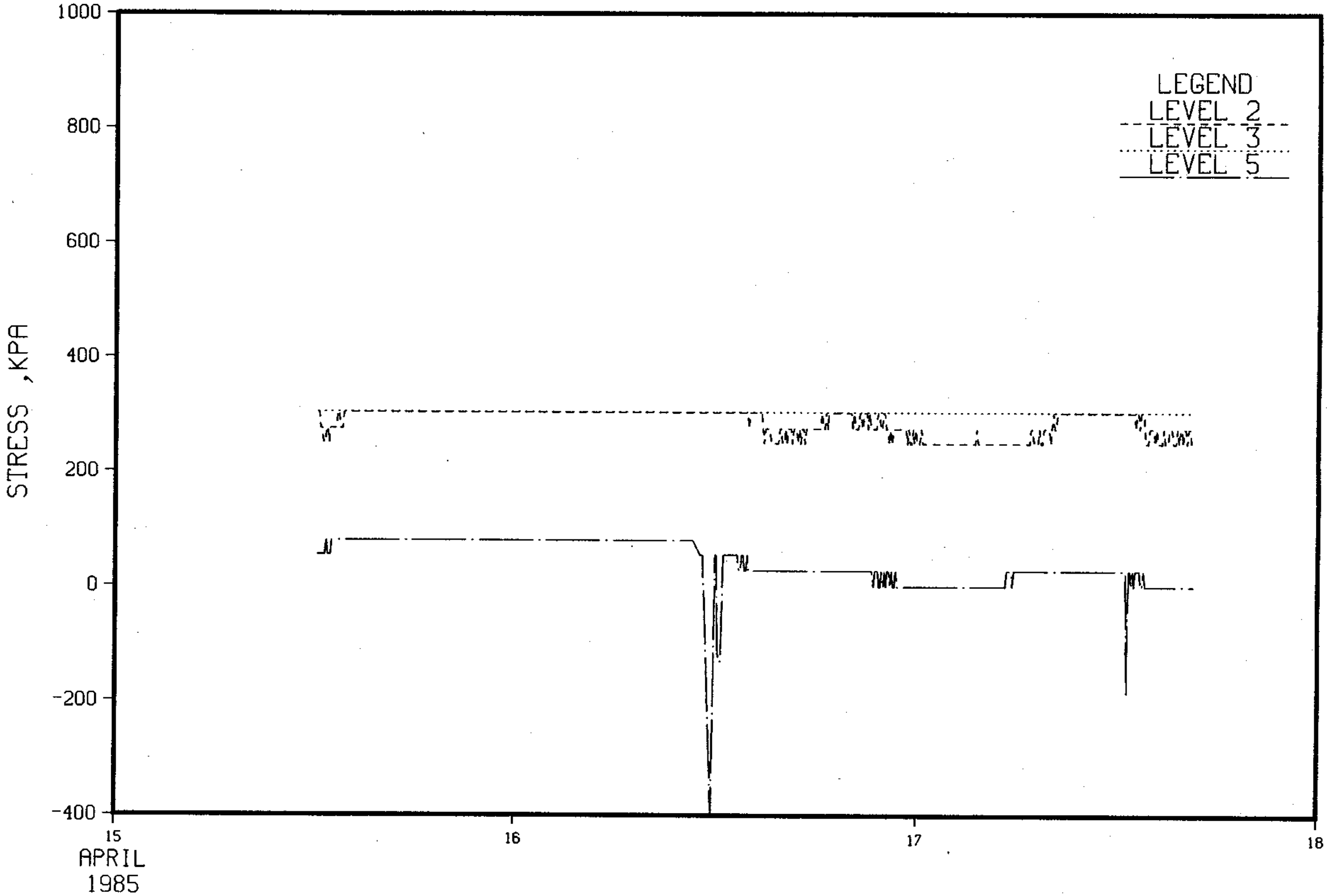
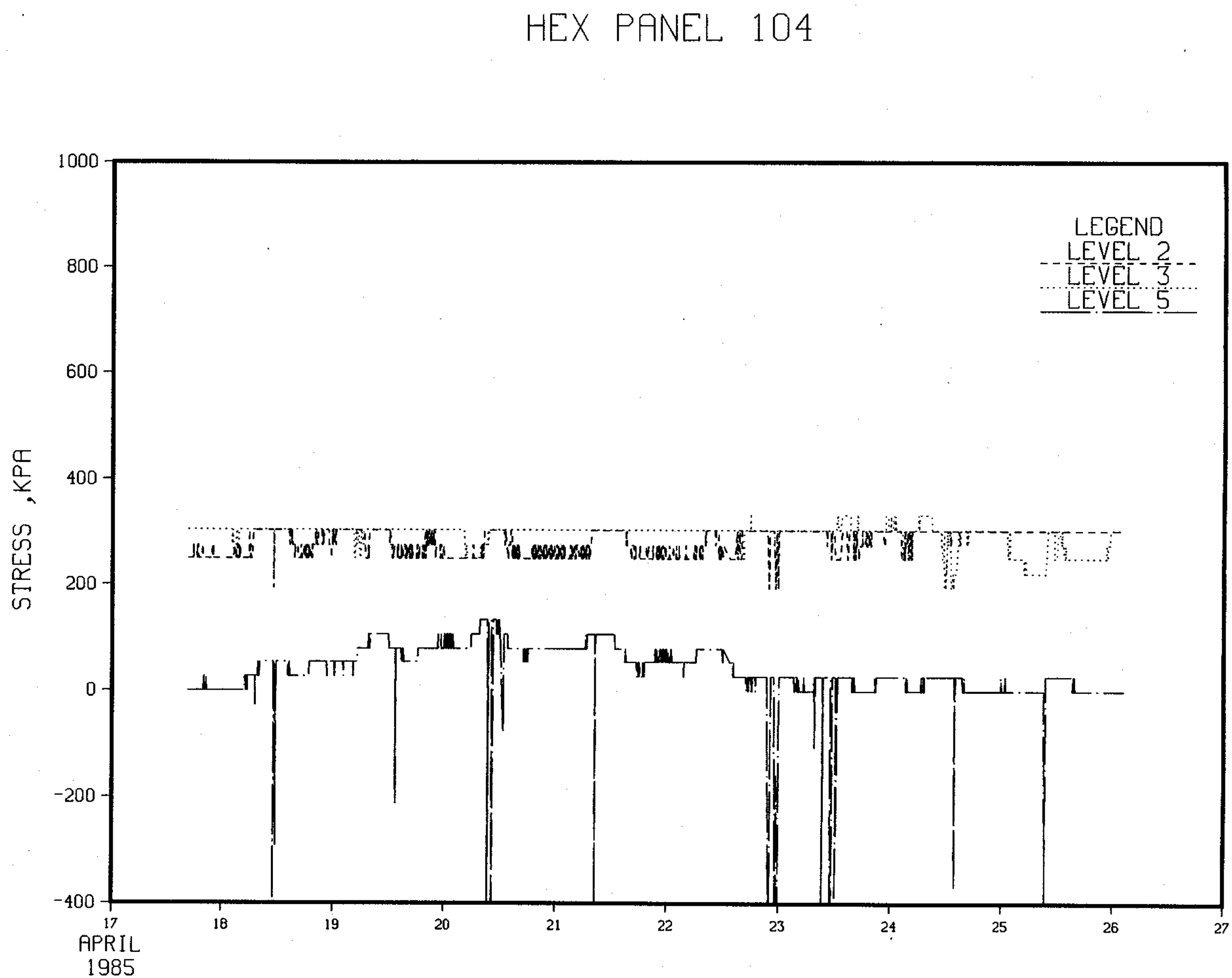


Figure 37



HEX PANEL 104
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STRESS ,KPA
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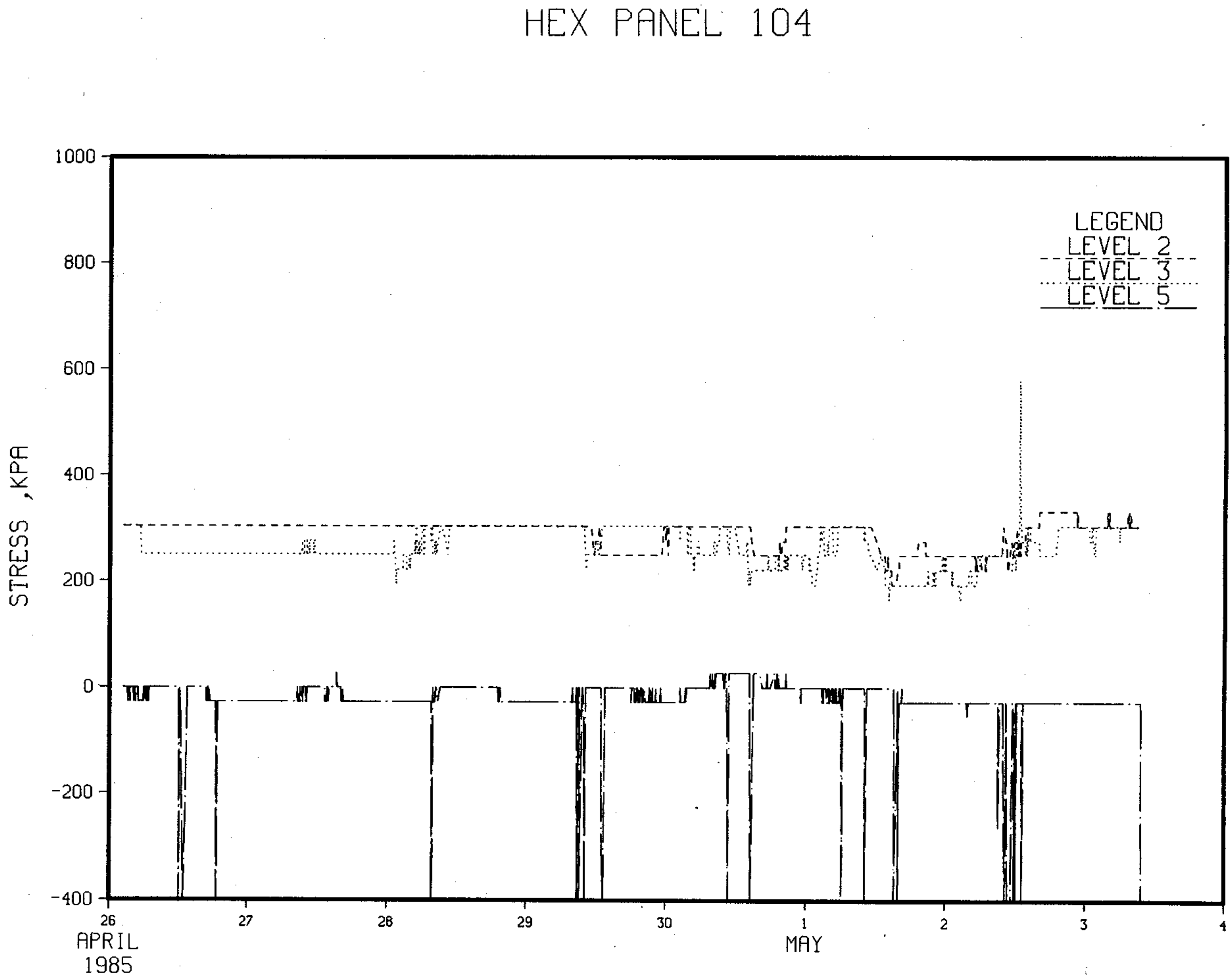
APRIL
1985

Figure 38



HEX PANEL 104
LEGEND
LEVEL 2
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LEVEL 5
STRESS ,KPA
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APRIL
1985
MAY

Figure 39

HEX PANEL 105

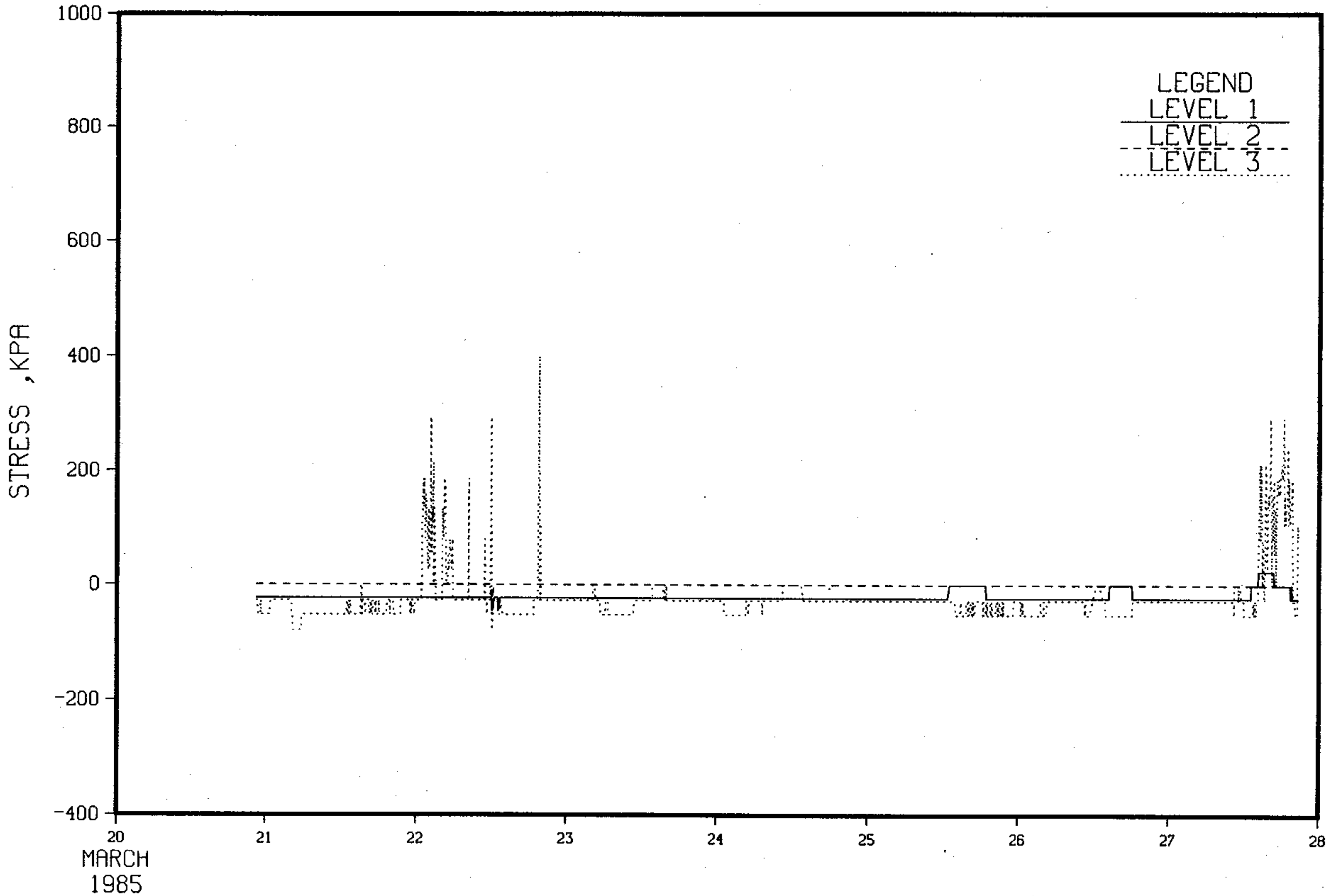
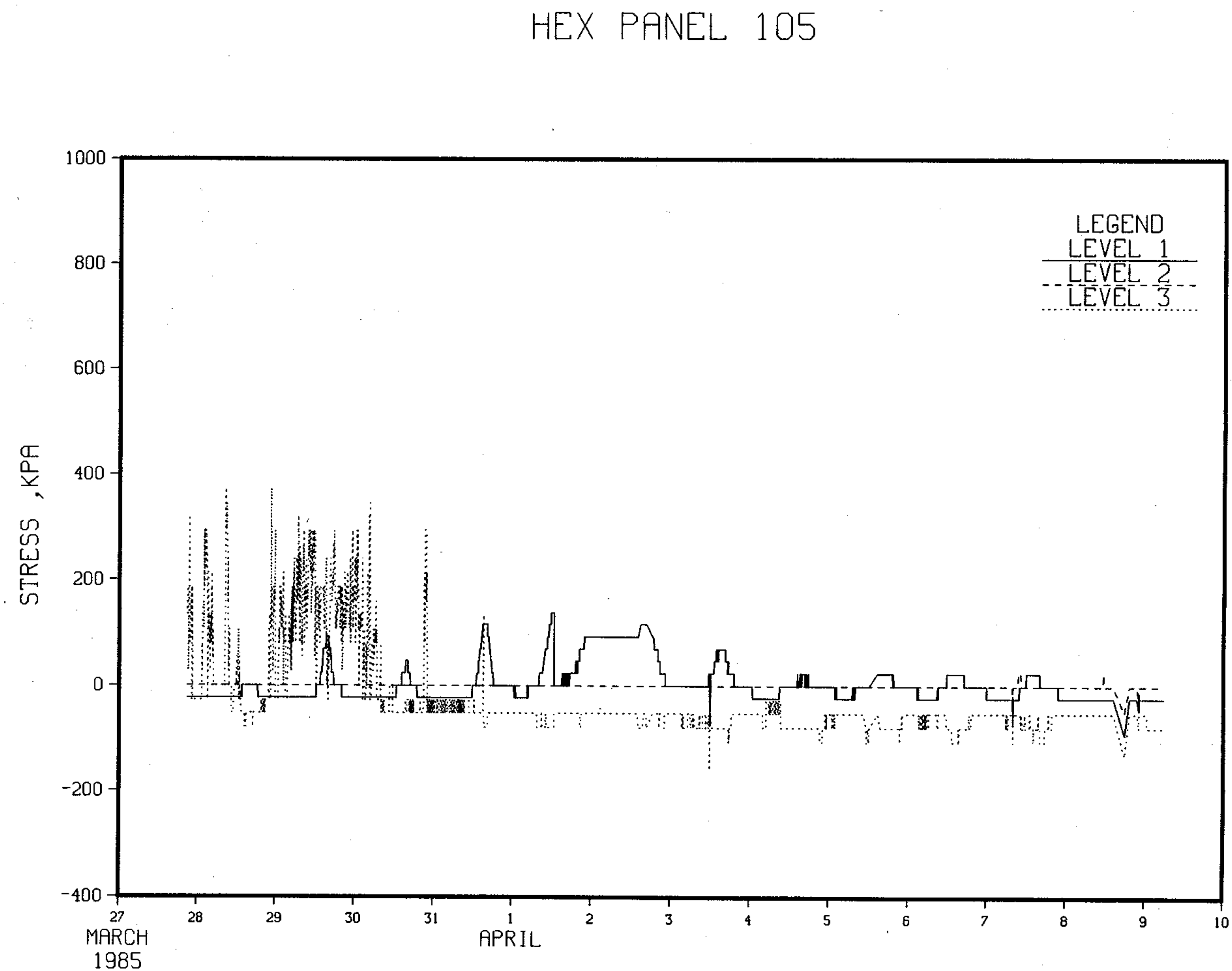


Figure 40


HEX PANEL 105
LEGEND
LEVEL 1
LEVEL 2
LEVEL 3
STRESS ,KPA
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MARCH
1985
APRIL

Figure 41

HEX PANEL 105

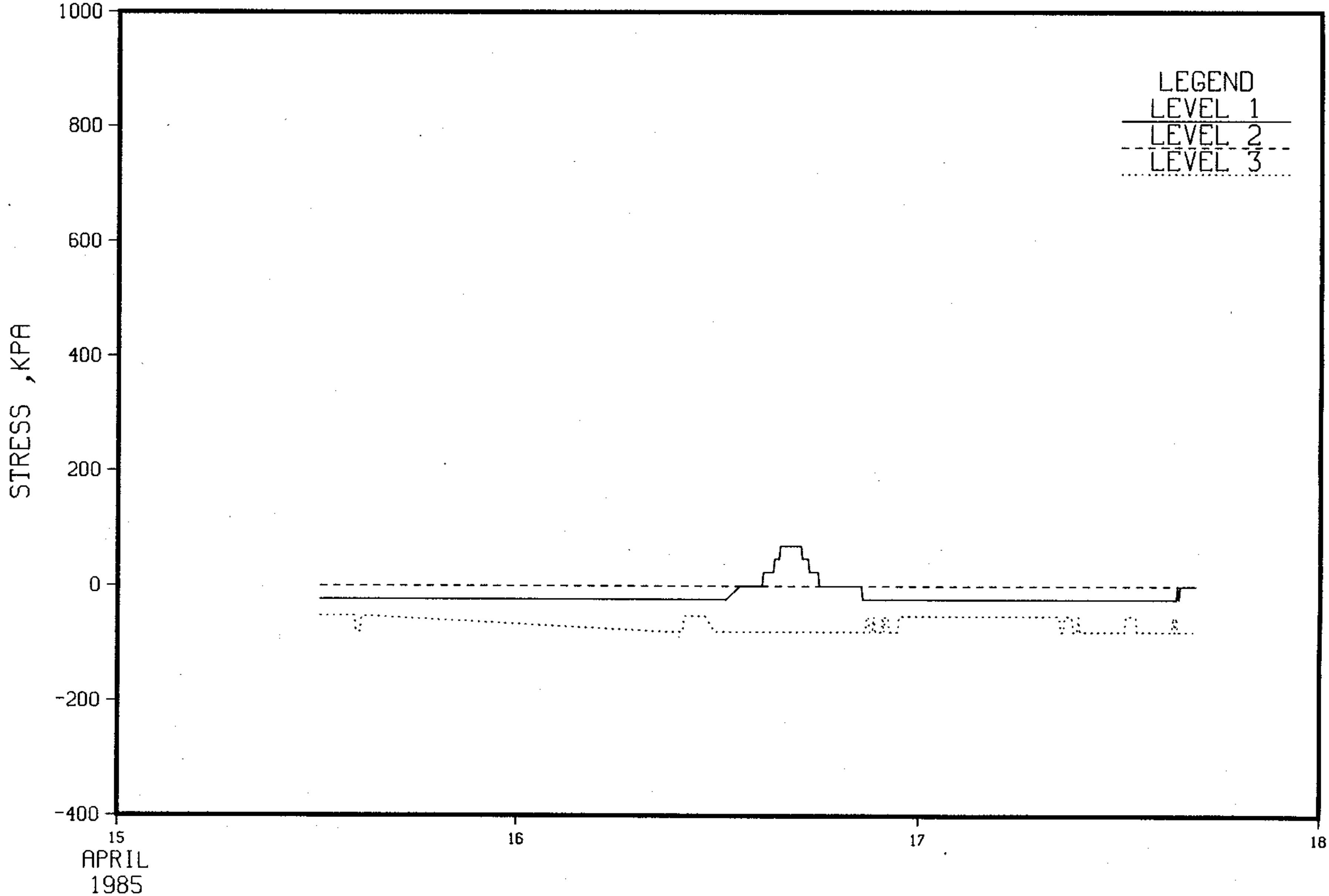


Figure 42

HEX PANEL 105

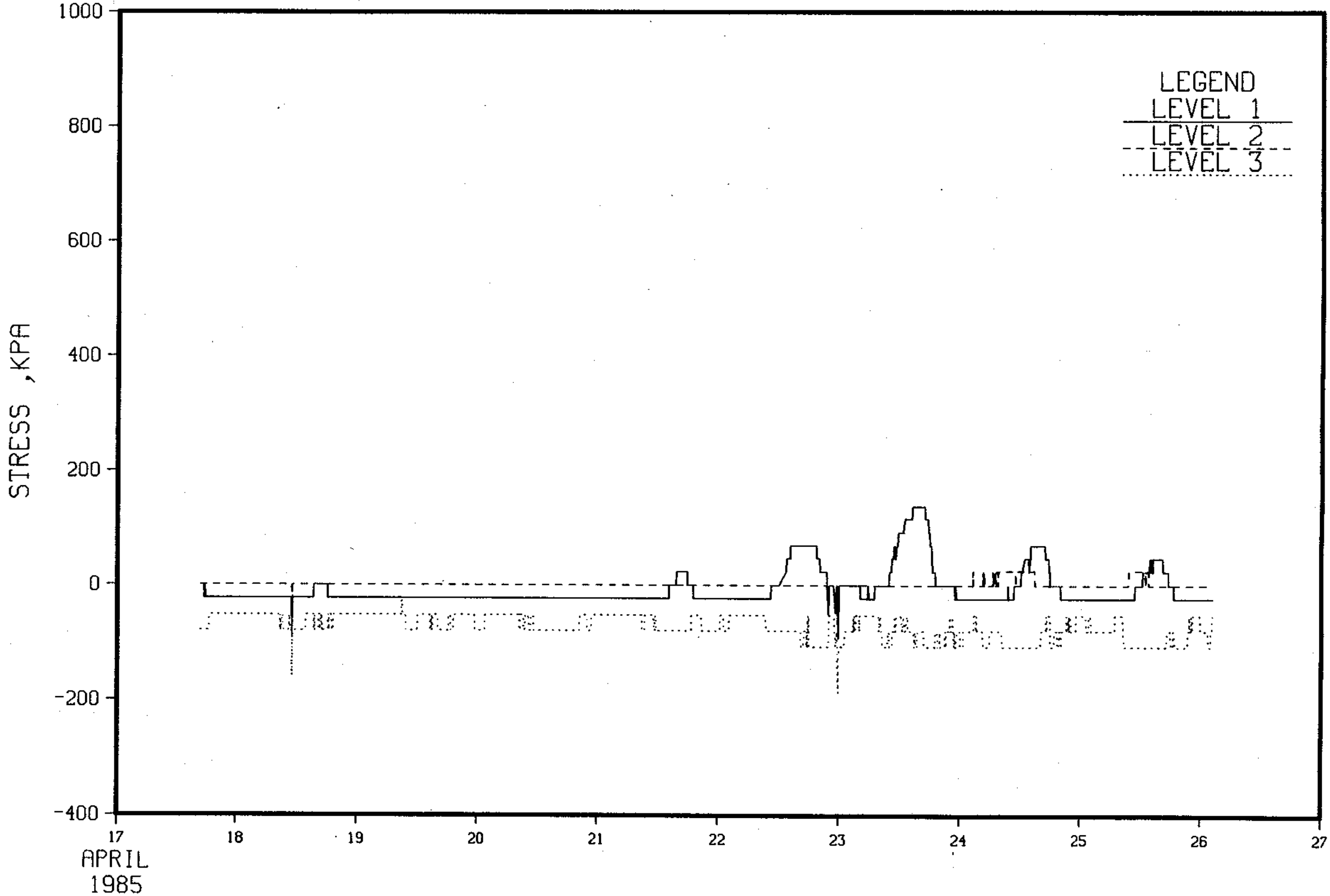


Figure 43

HEX PANEL 105

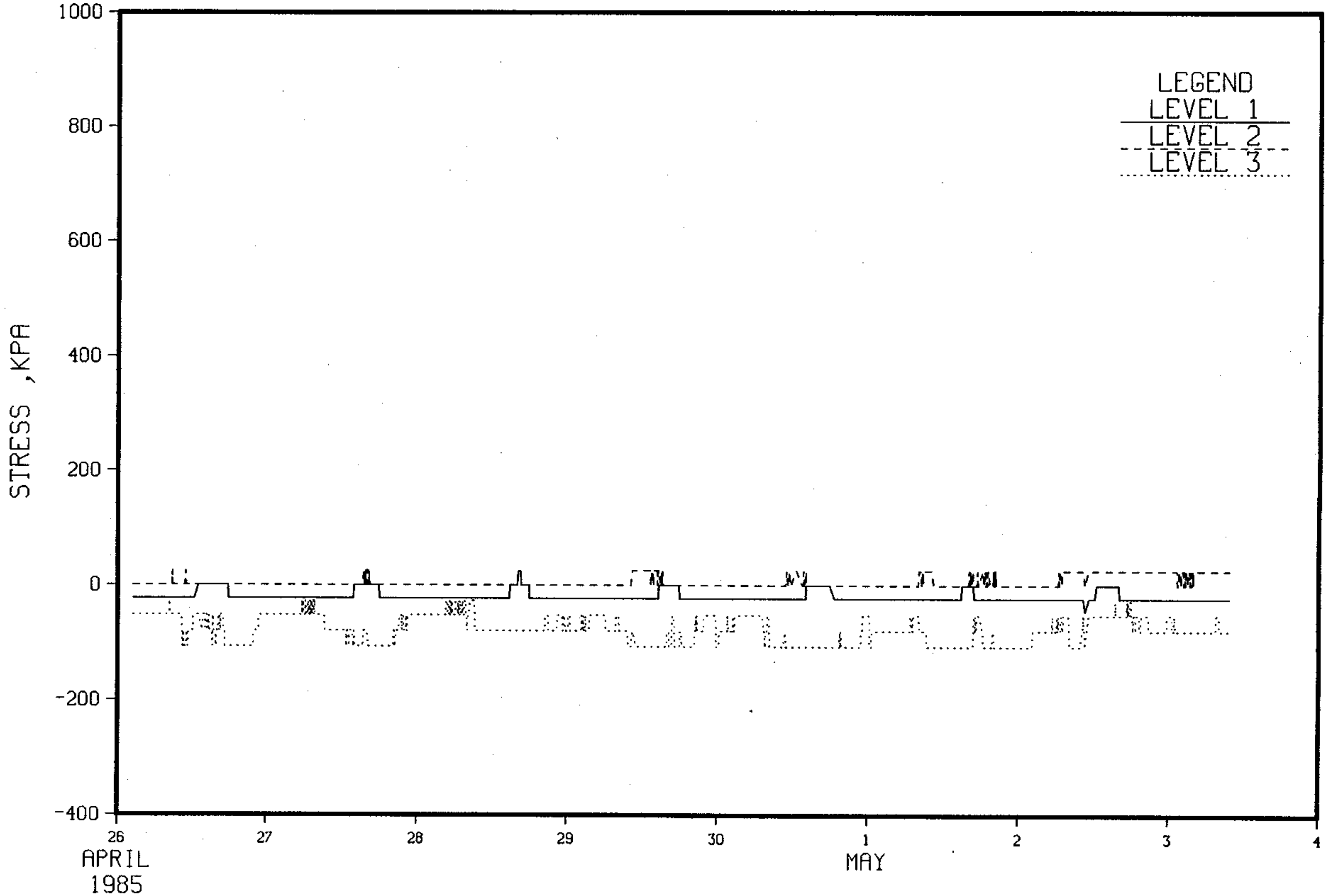


Figure 44

CMEL SENSOR,CH.1

Note for this sensor, 100mV = 100kPa(approx)

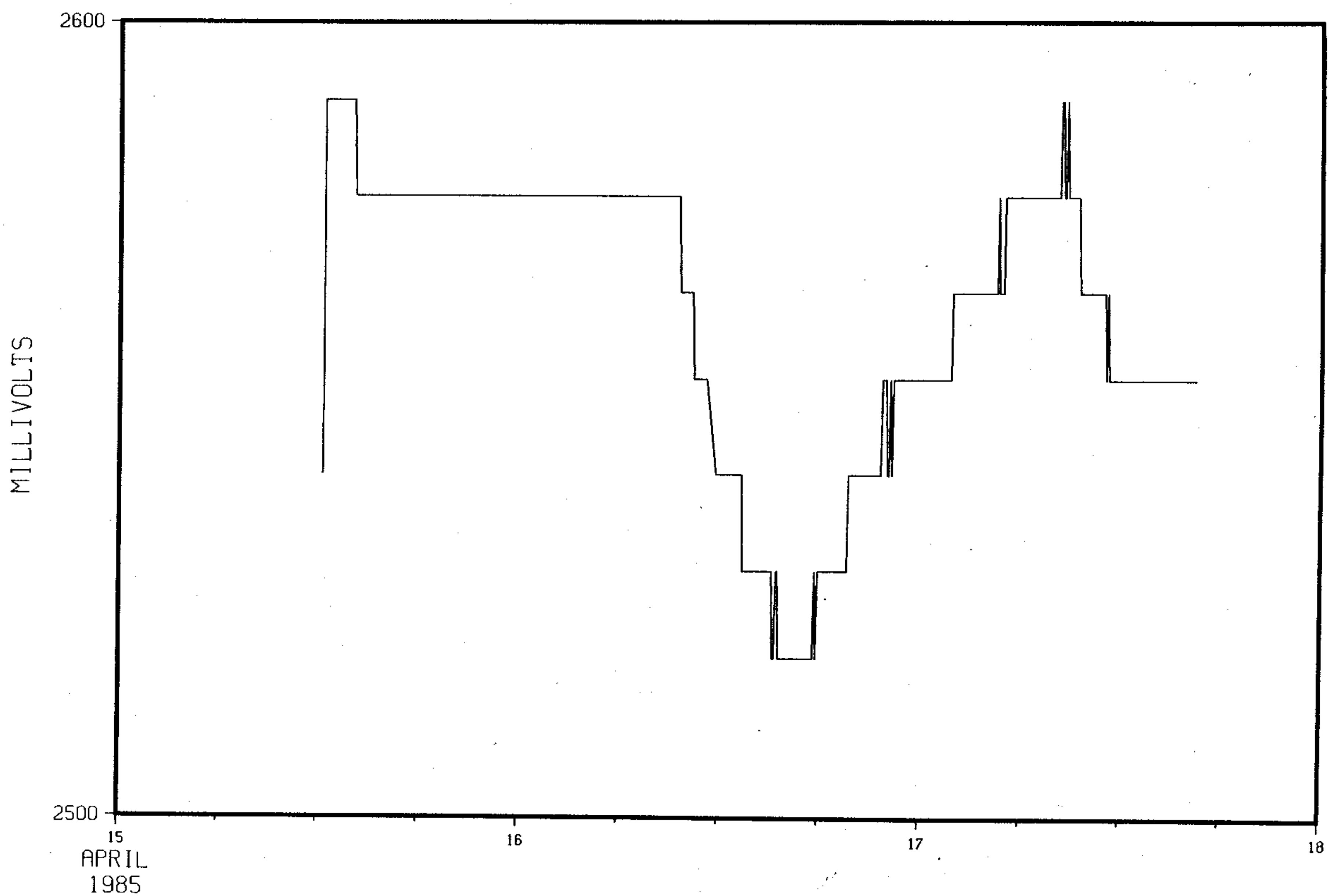


Figure 45

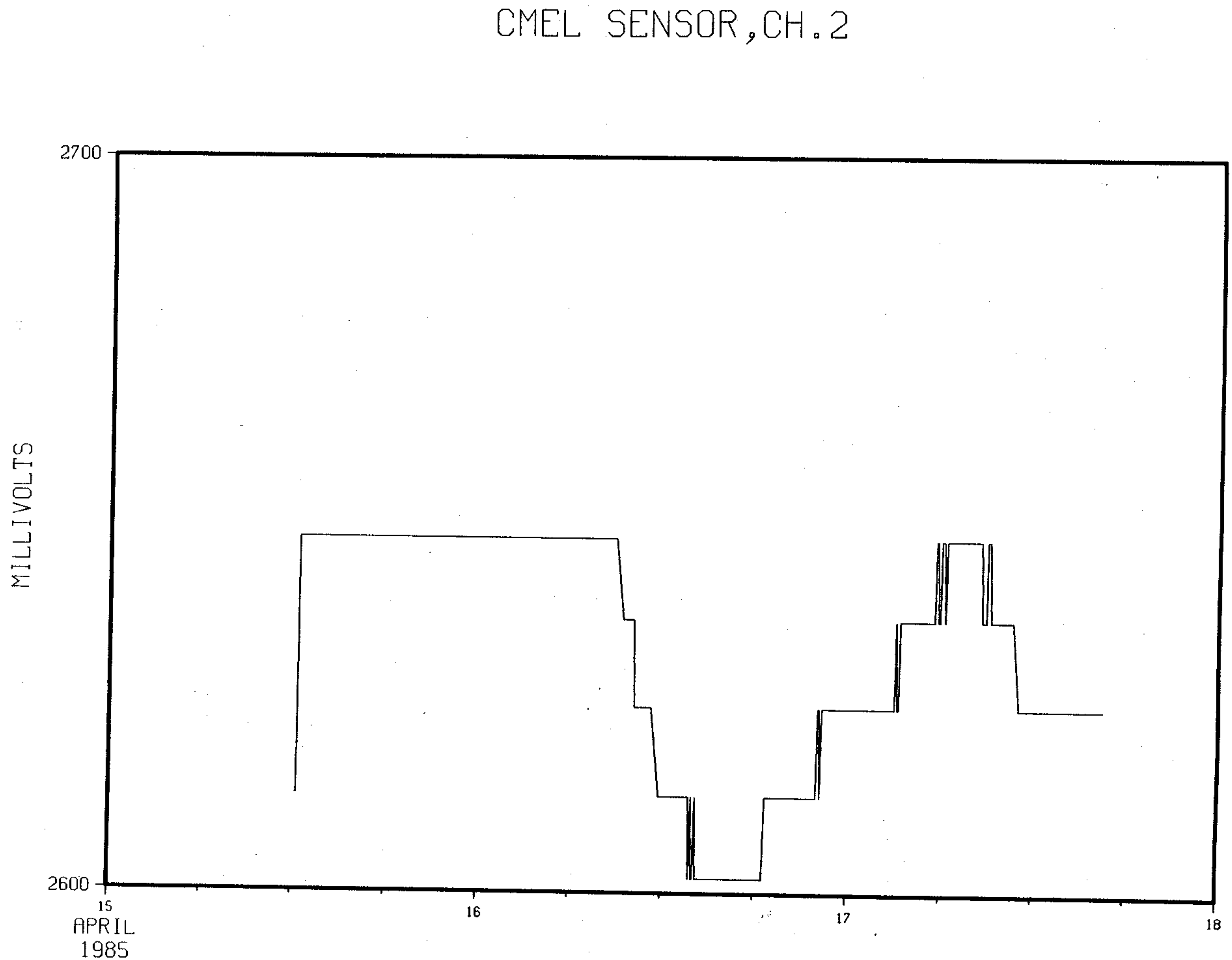


Figure 46

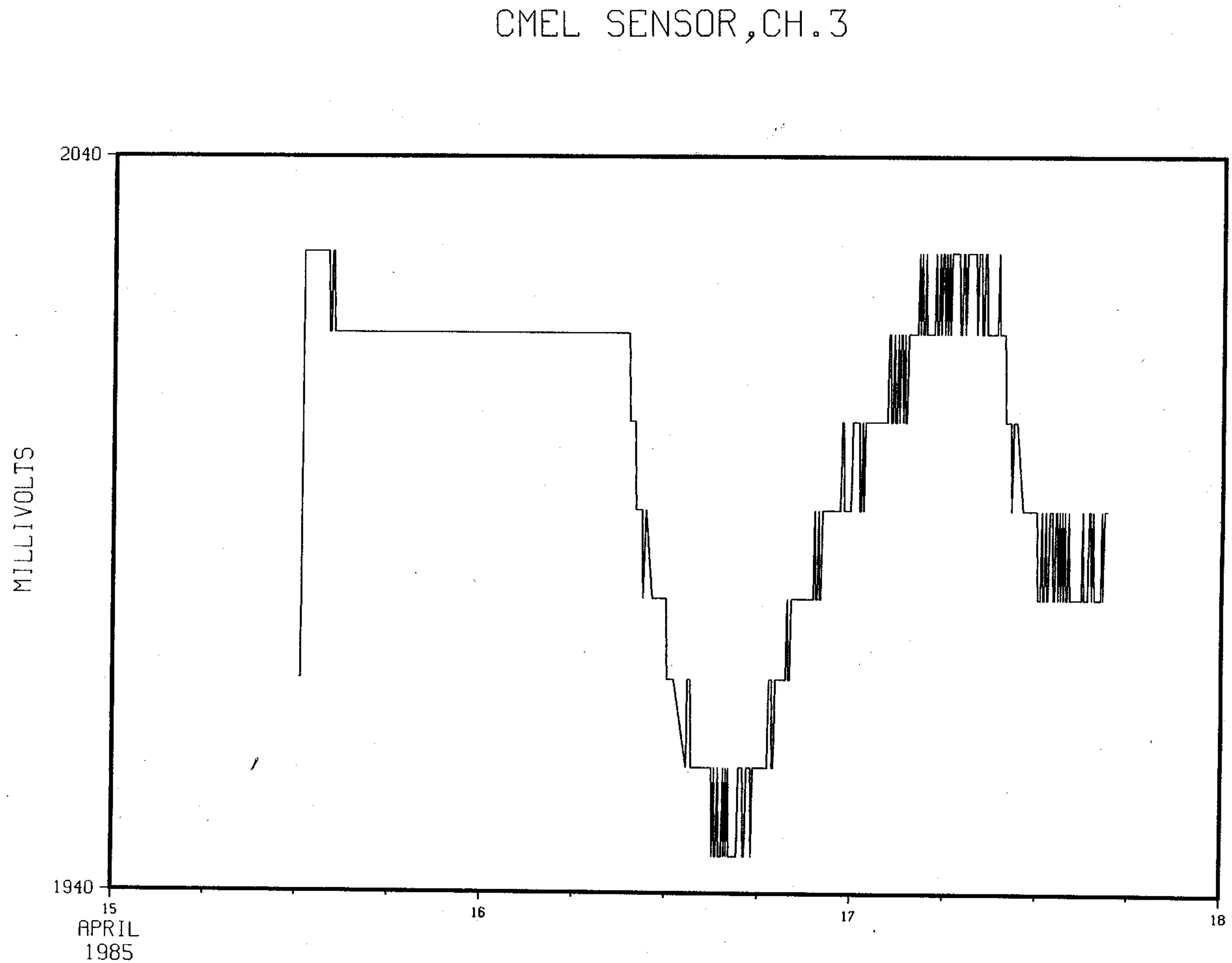


Figure 47

CMEL SENSOR, CH. 1

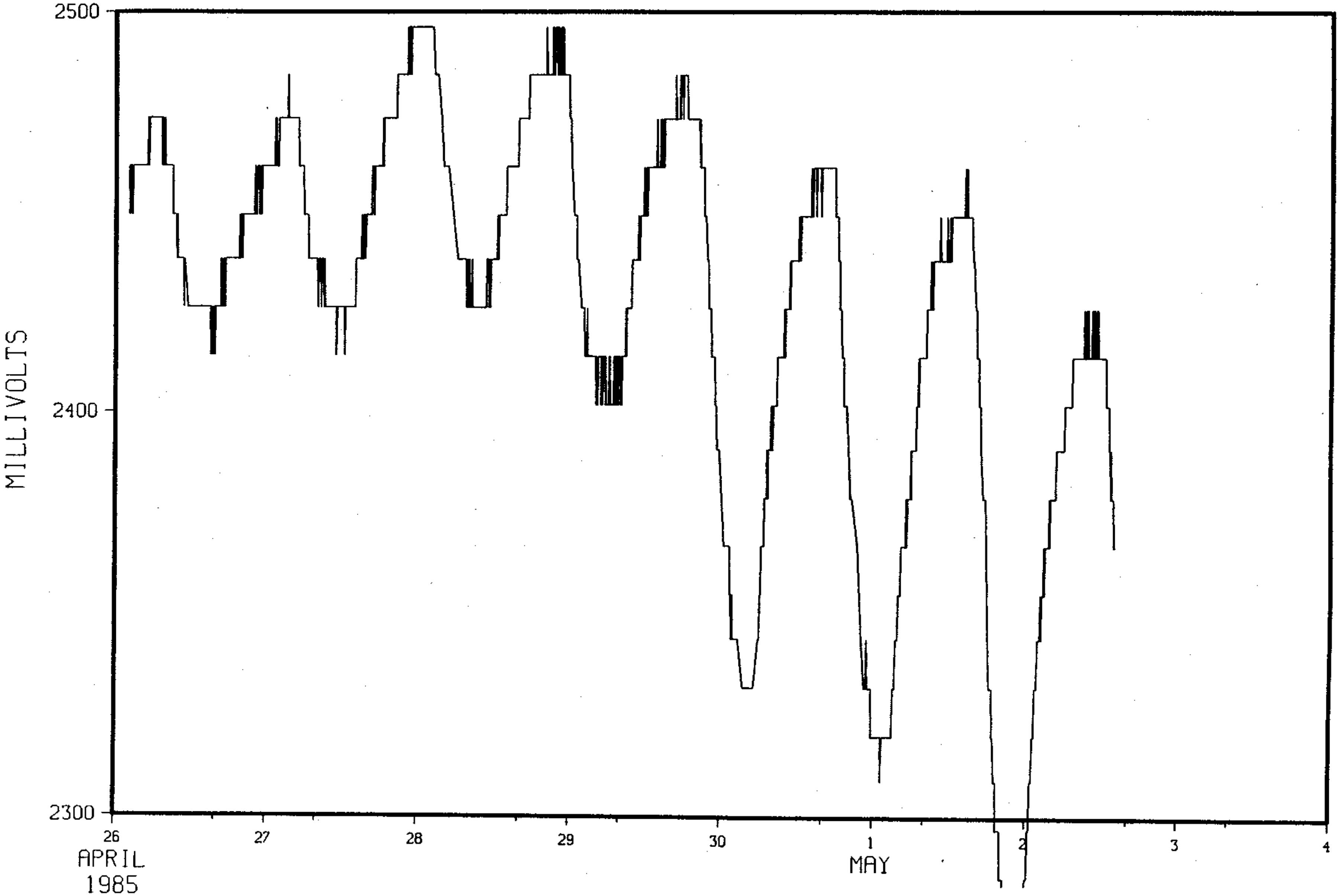
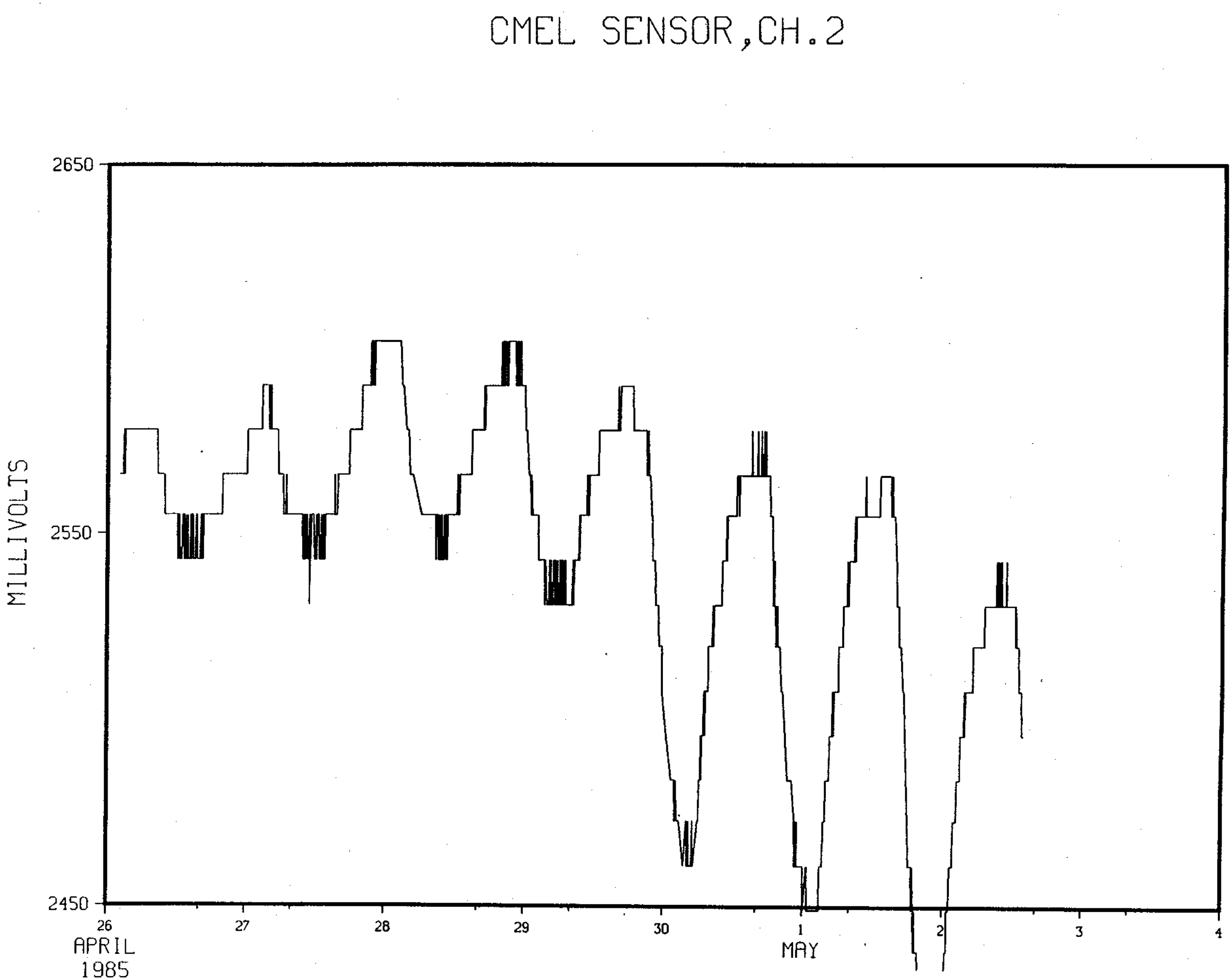


Figure 48


CMEL SENSOR,CH.2
MILLIVOLTS
2650
2550
2450
26
APRIL
1985
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28
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30
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MAY
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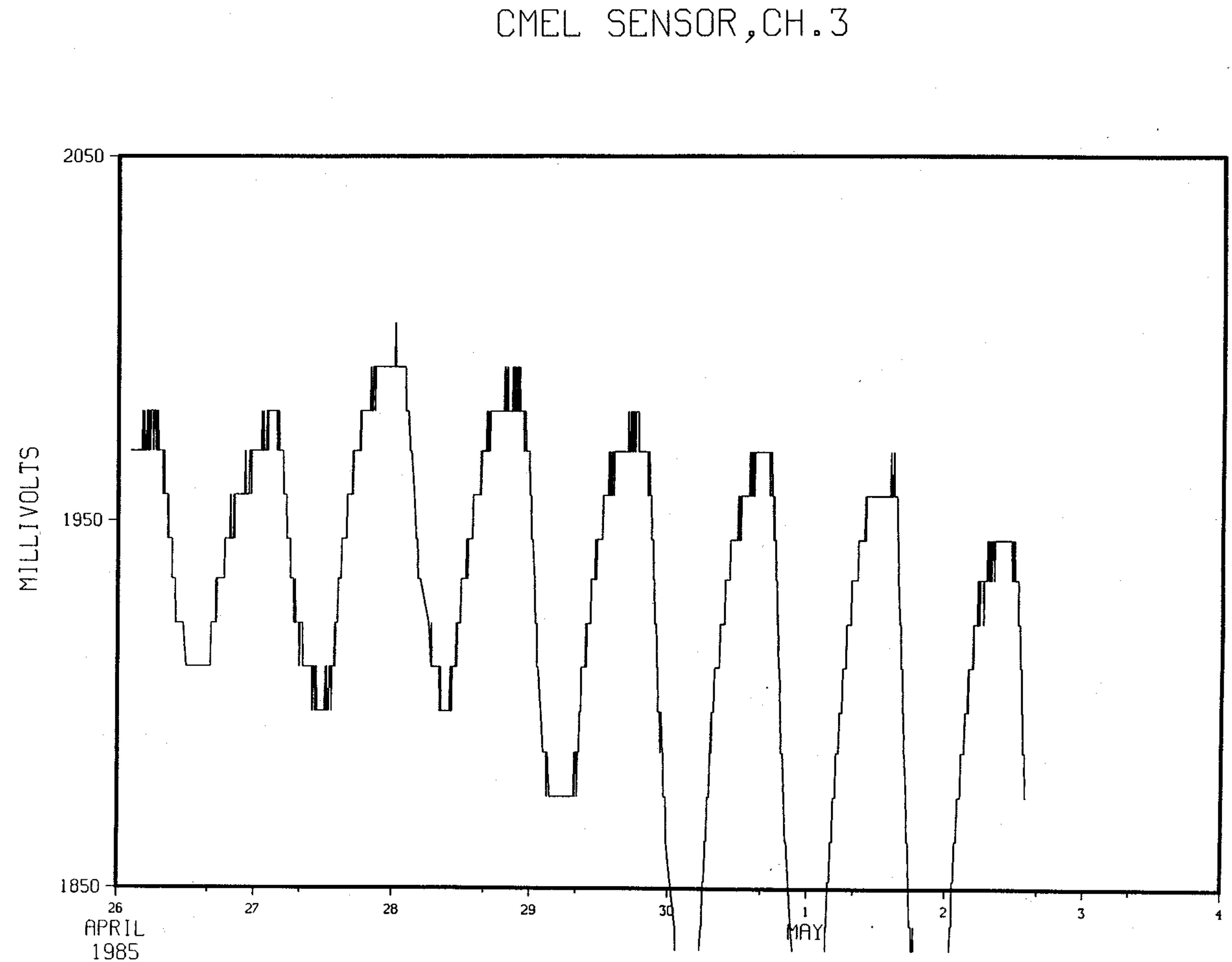
Figure 49


CMEL SENSOR,CH.3
MILLIVOLTS
2050
1950
1850
26
APRIL
1985
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30
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MAY
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Figure 50

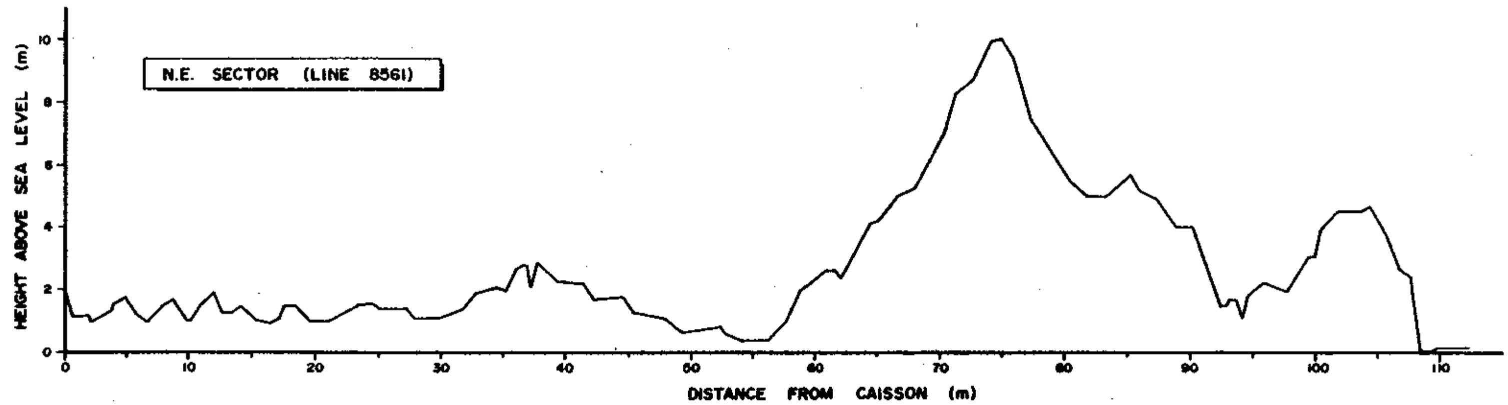


Figure 51

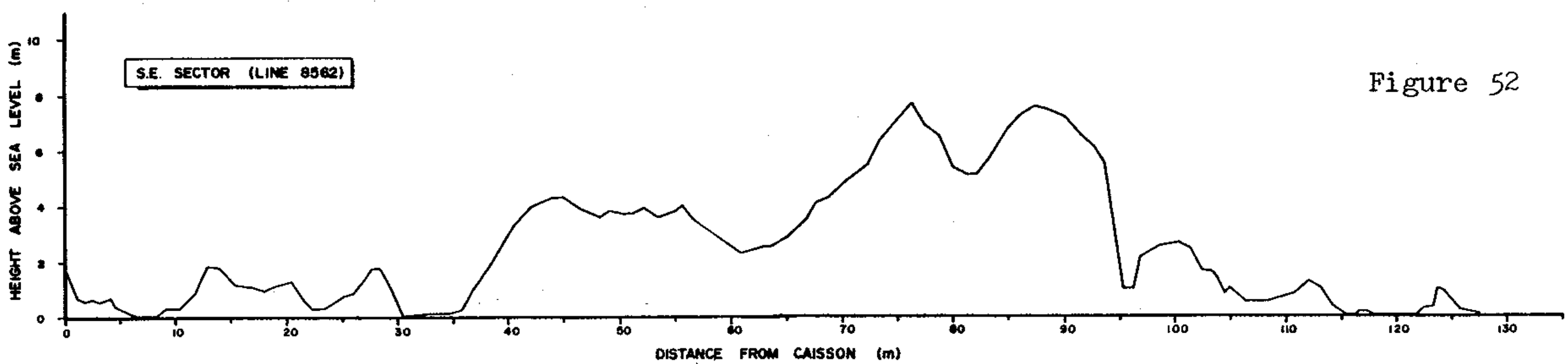


Figure 52

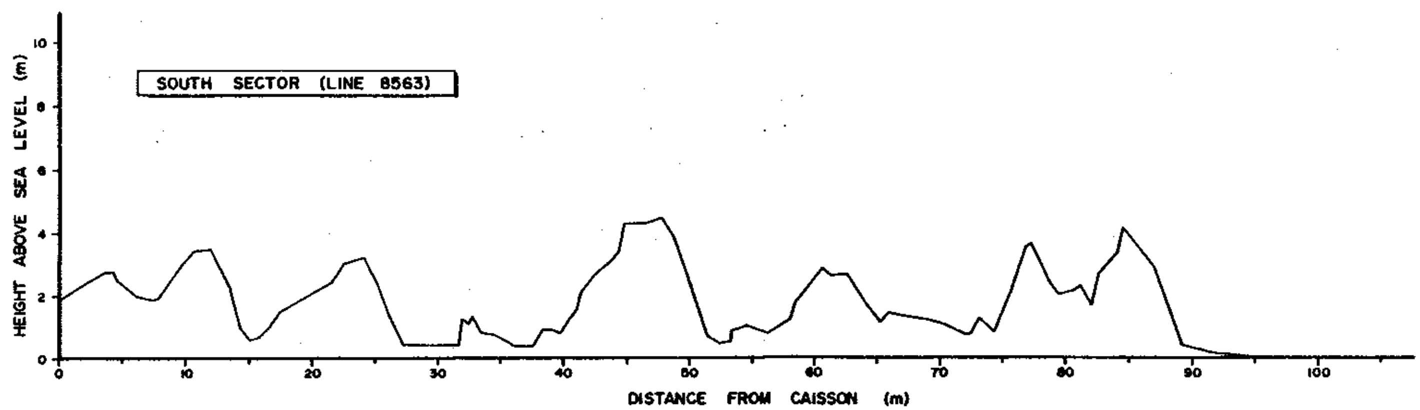


Figure 53

PROFILES OF RUBBLE FIELD SAIL

LINES OF PROFILES

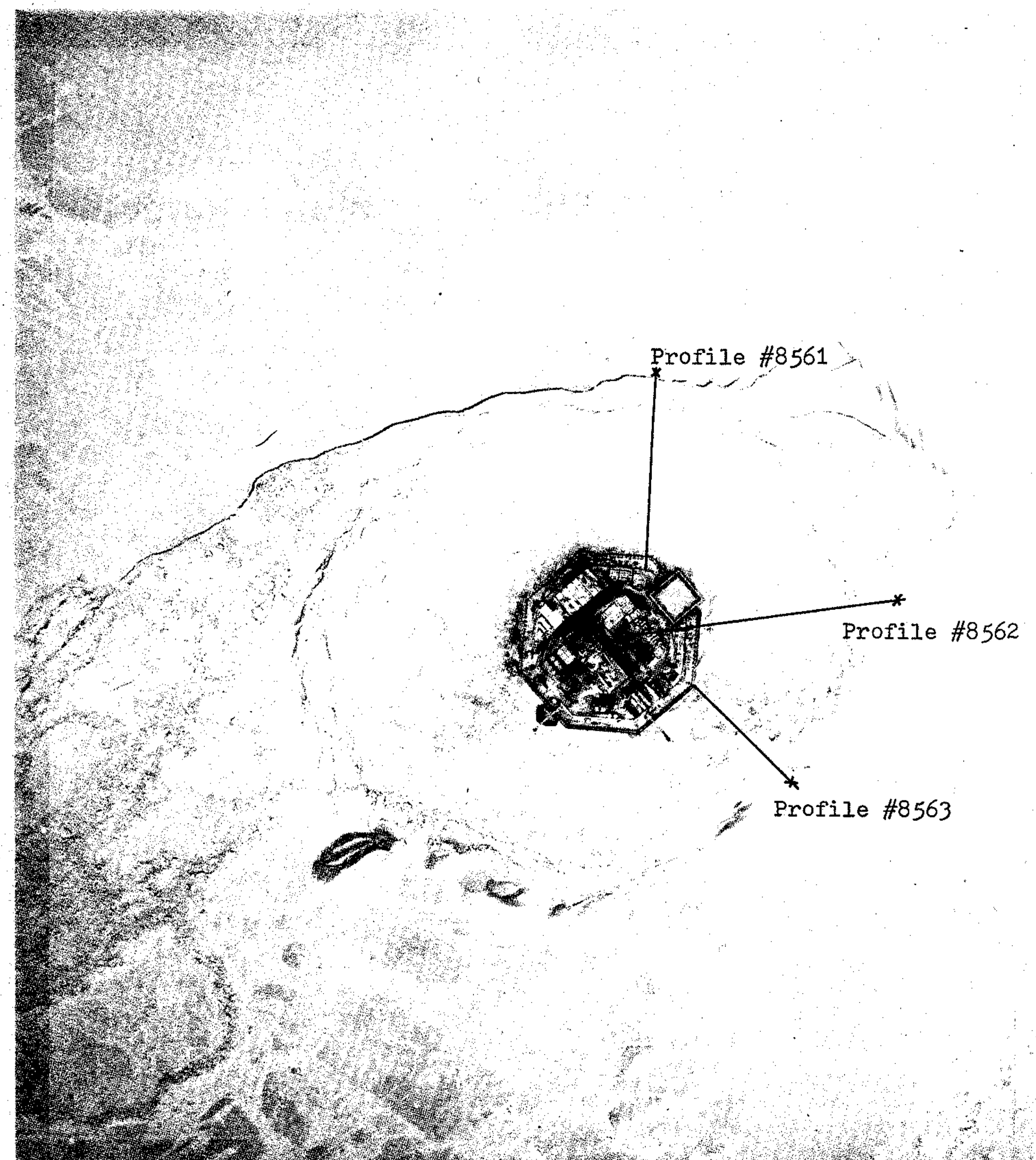
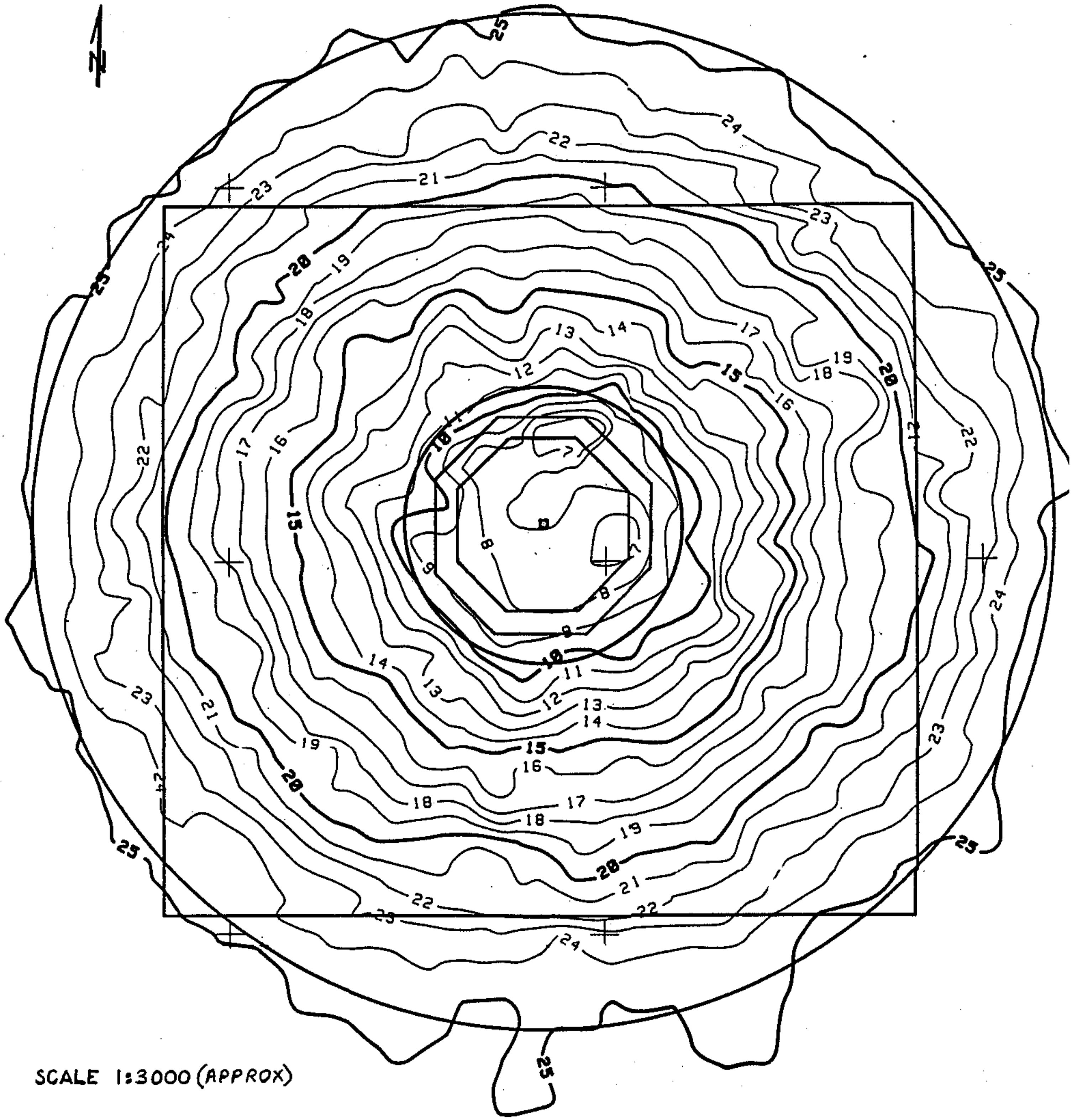
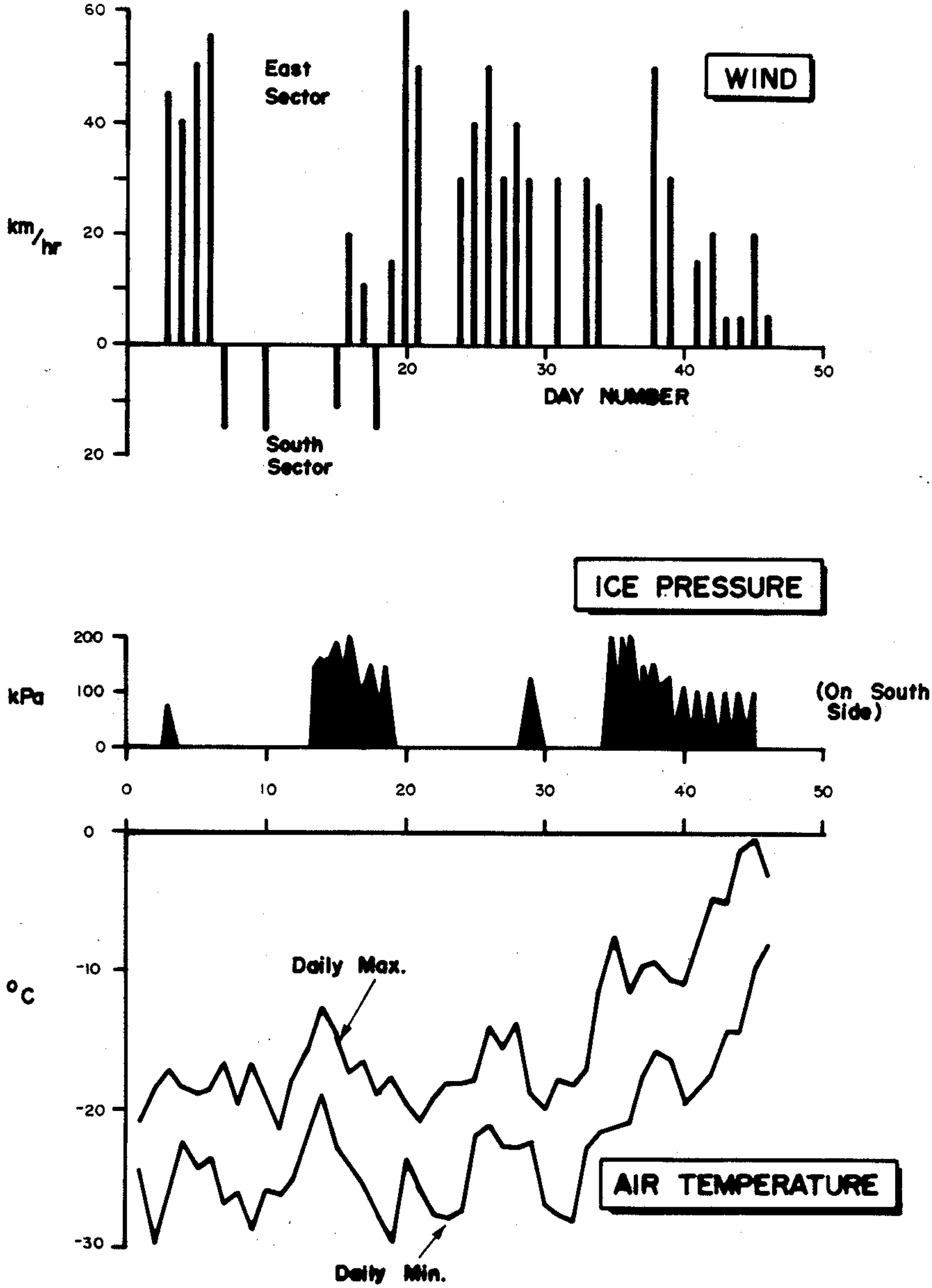


Figure 54



BERM BATHYMETRY (SUPPLIED BY ESSO)

Figure 55



COMPARISON OF ICE PRESSURE WITH WINDS AND TEMPERATURE

Figure 56

APPENDIX A

Description of the Esso CRI and Instrumentation

The Esso Caisson-Retained Island data acquisition system

C.Y. DER
Research Department
Esso Resources Canada Limited
Calgary, Alberta

ABSTRACT

In the fall of 1983, Esso Resources Canada Limited will construct a Caisson-Retained Island (CRI) at Kadluk 0-07 in the Beaufort Sea. Upon completion of this new island, a $2 million instrumentation system developed by the Esso Research Department will be put into operation to gather environmental and performance data.

Approximately 300 sensors will monitor the island's structural and geotechnical responses to the environmental forces. These sensors will be connected to a network of data acquisition subsystems controlled by three distributed computers. The data collected will be used to add to the safety of operations on the island. It will also allow Esso to optimize the design of future Beaufort Sea offshore structures, and will extend our insight into the environmental conditions in this area.

Background

Esso Resources Canada Limited has been very active in Beaufort Sea exploration for more than a decade. During this time, Esso has pioneered the design and construction of sacrificial-beach, artificial islands (eighteen to date). Recently the lack of local (Western Beaufort) sources of fill materials having good soil propeties, and the poor economics of long haul distances have directed Esso's ongoing research toward alternative artificial-island technologies. This led to the development of Esso's first Caisson-Retained Island (CRI).

Figure 1 shows the complete ring of linked, steel caissons which will form the outer perimeter of the island. The ring is made up of eight caissons each weighing approximately 50,000 kN (5000 tons) when fully ballasted. The caisson ring is set down on a prepared subsea foundation (berm) and the interior of the ring is filled with dredged sand. This type of island has the advantage of requiring significantly less sand fill as compared to sacrificial-beach islands. In addition, the caisson ring can be disconnected and moved to other locations for re-use.

Simultaneously with the design and construction effort of the CRI, the Esso Research Department designed an extensive $2 million instrumentation system for the island. This system is currently in its final development stage and will be operational by the fall of 1983 when the CRI is installed at its first location. The entire instrumentation program for the CRI is expected to require a commitment of eight to ten man-years over the next three years.

The requirement for an instrumentation system was identified early in the CRI project to accomplish the following:

- ADD to the safety of island operations;
- OPTIMIZE the design of future caissons, or other Arctic structures; and
- SUPPORT Arctic research studies using the caisson island as an observation platform.

To achieve these objectives, the system was designed to collect data on key environmental and CRI performance parameters, such as:

- local and global ice forces;
- ice sheet and rubble movements;
- geotechnical forces and movements;
- caisson stress and movement;
- wind and current velocities; and
- wave heights.

System Design

Over-all Requirements

The unique structure of the CRI and the severe Arctic environment in which it will reside, were major factors in the

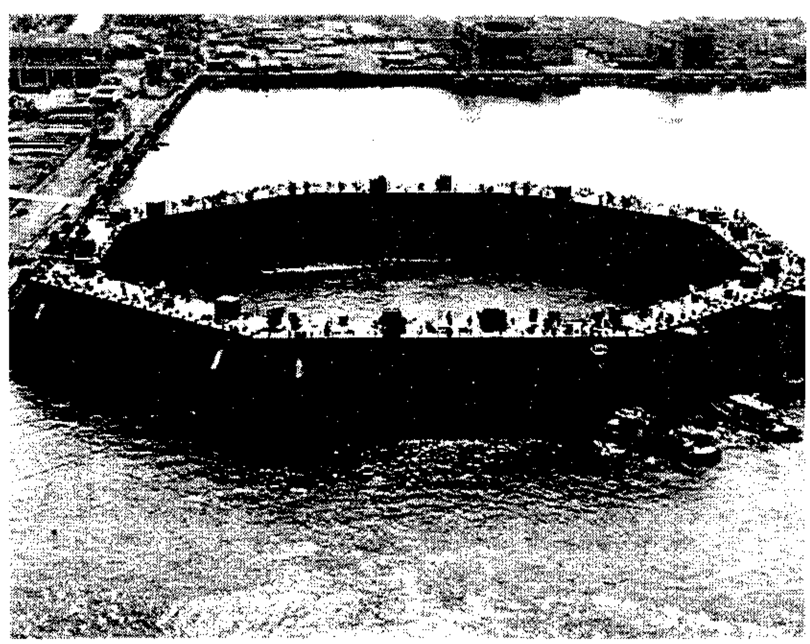


FIGURE 1. Photograph of Caisson ring in shipyard.

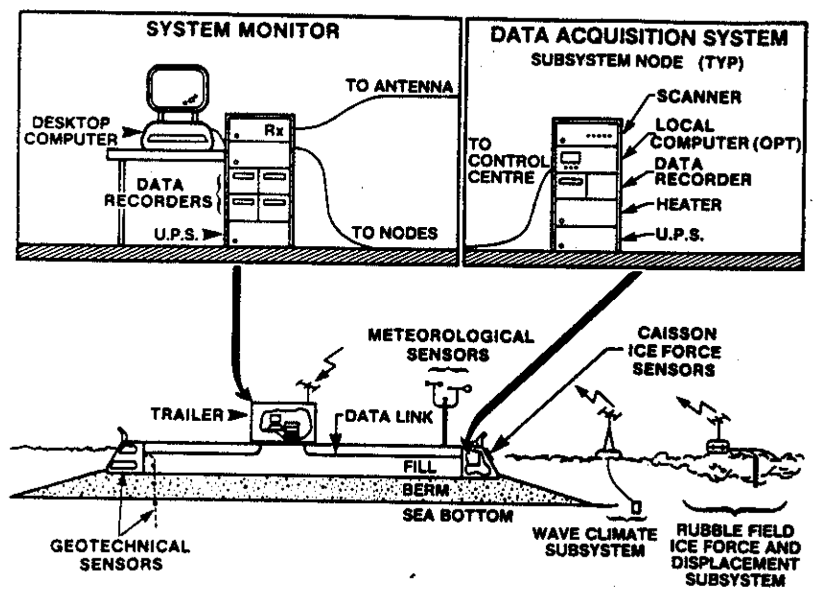


FIGURE 2. CRI instrumentation system concept.

design objectives of the instrumentation system: low support requirements, system flexibility, and high reliability.

"Support requirements" are the space and manpower needed to operate the instrumentation system. Both these items are limited by location and cost.

In our application, "system flexibility" means the capability to downgrade or upgrade the system to meet a range of diverse functional requirements. This arises from the need to monitor and collect data during the initial installation phases of the CRI. At these times, the instrumentation system must be easily adjustable to the situational requirements.

Finally, the system must be highly reliable. Fault tolerance and built-in component redundancy are necessary elements of the system design. This is to minimize loss of data, as well as to avoid unscheduled maintenance and repair. The latter is extremely costly because of the logistics and economics of working in a remote area such as the Beaufort Sea.

Distributed vs Centralized System Design

The objectives were met with a distributed system design. A distributed system has two attributes which are advantageous in the CRI application. The first is that a number of processors or computers are physically "distributed" or spread throughout the system. The second attribute is that the system task, such as a data acquisition, is "distributed" or subdivided among the processors.

For the CRI the more traditional single, central data acquisition and computer system would have severe shortcomings. A centralized system not only requires more surface space, but also creates a cable concentration problem on the island because all cables converge and connect at a central location. Although the CRI will have a diameter approximately the length of a football field when complete, the camp, drilling rig, and supply requirements demand most of the available surface space. This lack of space and the concentration of heavy equipment and activity at the centre of the island means that the survival rate of instrument cables (even protected cables), run on the island surface or even buried a few feet below the surface, would be unacceptably poor.

These difficulties are avoided with a distributed design in which the instrumentation system is organized as a network of small, self-contained data acquisition "nodes". A typical node consists of a "smart" scanner connected to a group or block of sensors. The primary functions of a node are the scanning of selected sensors (multiplexing), digitization of the analog signals from the scanned sensors (A/D conversion), and data transmission to recording tape units. By engineering each node to fit within the space available inside individual caissons, the requirement for island surface space is substantially reduced. The operator interface, or system monitor, is left as the only part of the system requiring surface space. This arrangement also keeps almost all of the sensor cabling within the protection of the caisson structure and away from the island interior.

As mentioned previously, the second advantage of a distributed system design is the subdivision of tasks. The scanners used in the data acquisition nodes are "smart" or "intelligent", in that they have their own microprocessors which allow them to be programmed to operate independently. The complete data acquisition task is then divided between the scanner and its local computer. This is called parallel processing and allows high execution speeds and high data throughputs.

Other Design Features

The modularization of the system into functionally independent subsystems, consisting of one or more nodes and a local computer, meets the design goal for system flexibility. In our design, system reconfiguration becomes a simple matter of adding or deleting the necessary subsystems. This also facilitates the orderly and organized development and construction of the system because the design, construction and testing of the subsystems can be done independently of each other. Bottlenecks and redundant activities are consequently minimized. Cost savings can also be realized since modularization allows the individual optimization of those subsystems which do not have to meet stringent requirements for resolution, accuracy or speed of measurement.

High system reliability is achieved because a distributed system is inherently redundant. In the various subsystems many system functions and components are duplicated. So, in the event of a component malfunction, the highest priority subsystem can be maintained at the expense of a lower priority subsystem. This arrangement optimizes the cost of maintaining a prudent level of component sparing and the cost of maintenance support.

System Description

Figure 2 gives a conceptual diagram of the CRI data acquisition system and Figure 3 shows a simplified island layout. The system is an organization of three basic functional blocks: a SENSOR block, a data collection NODE/SUBSYSTEM, and a system MONITOR.

Sensors

Approximately 300 sensors will be connected to the instrumentation system. They fall into two broad categories:

- those which measure environmental forces (e.g. ice forces, wind, waves, currents) or environmental conditions (e.g. air, soil and ice temperatures, relative humidity); and
- those which measure the reactions of the CRI (e.g: caisson structural stresses, caisson and berm movements).

The sensors are located either on the caisson structure or within the island in the sandfill, the berm or the sea bed. Canadian technology and expertise provided much of the special sensor cabling and some of the sensors used on the caissons. In particular, the special ice-force sensors were developed by two experienced Canadian firms, Arctec Canada Limited and Weir-Jones Engineering Consultants Limited.

All of the sensors are direct-wired to

the subsystem scanners to maximize their reliability. The sensor cables are low temperature, marine cables specified for the Arctic environment. They are grease-blocked to minimize electrical leakage arising from pinholes or breaks in the cable jackets because of wear or aging. The instrumentation system uses approximately 9 km of this type of sensor cable.

Nodes and Subsystems

Figure 4 is a functional block diagram of the instrumentation system. There are three data collection subsystems: high-speed, low-speed, and remote. The high- and low-speed subsystems include a local computer, one or more node scanners, and a battery of sensor signal conditioning units.

The local computer processes the digitized data from its node scanners. This includes averaging the sensor signals, computing statistics and checking the signals against preset threshold values. The computer is also programmed to adjust the rate at which data are collected and recorded by monitoring data trends and making decisions based on these thresholds, as well as other conditions and priorities. The processed data is subsequently stored on magnetic tape. The local computer is connected via the data communications network to its own dedicated tape unit located in the instrumentation trailer with the system monitor. This location provides a better controlled environment for the tape units and allows easy tape maintenance. In addition, backup tape units reside with the local subsystem computers in the same equipment cabinet. These secondary tape units are put into service whenever the full communications network is not in place or a data link fails.

The system design placed a number of special requirements on the local computer. A compact, complete stand-alone unit was required to fit in the available cabinet space inside the caisson. In addition, we needed a computer having a suitable hardware and software environment on which to implement real-time, adaptive data processing. This scheme (discussed later) involves the self-adjustment of operating parameters to optimize the data collection. It requires a fast processor, a large memory capacity and a high data throughput capability for successful implementation. Based on these requirements, we selected the Hewlett Packard HP9826A computer.

Approximately 100 sensors are connected to each of the nodes in the high-speed subsystem. Because most of these monitor rapidly changing parameters (e.g. structural stresses) or peak events, the node scanners are required to have a minimum capacity of 100 data channels and a capability of gathering data at a maximum rate of 10 samples per second per sensor (or a burst sample rate of 1000 samples per second). However, normal operation will involve a nominal rate of 1 sample per second per sensor (or 100 samples per second).

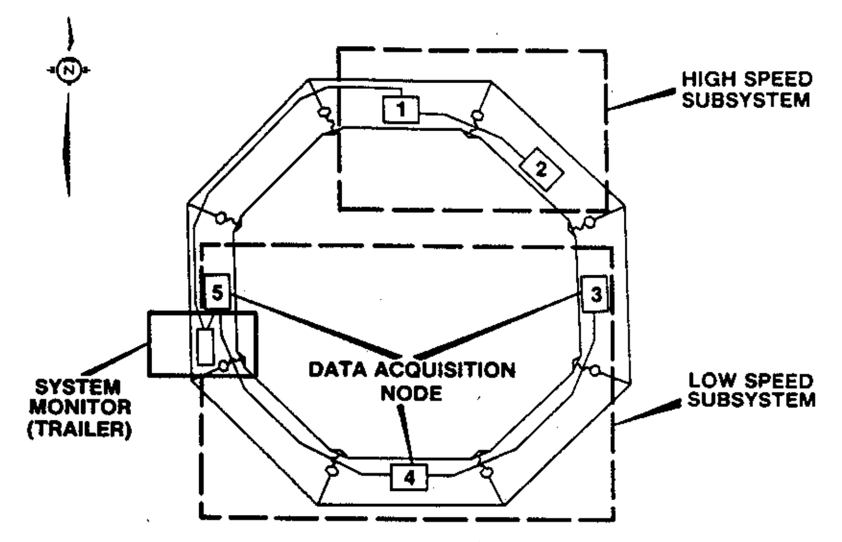


FIGURE 3. Simplified island layout for CRI instrumentation system.

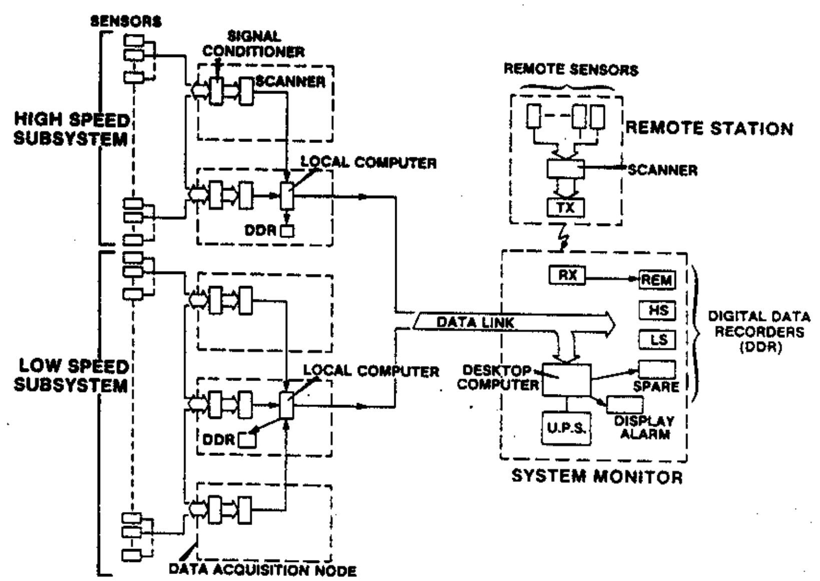


FIGURE 4. CRI instrumentation system functional block diagram.

The low-speed data acquisition nodes handle fewer sensors than the high-speed nodes. The sampling rate requirement is also lower because the sensors primarily monitor slow response parameters such as soil temperatures.

An evaluation of various state-of-the-art data acquisition scanners led to the selection of two Hewlett Packard units for our application. The HP2250 Measurement and Control Processor best met our requirements for sensor capacity, data acquisition speed and local intelligence. It is used in the high-speed subsystem, while the HP3497 Data Acquisition and Control Unit was our choice for the low-speed subsystem.

The high and low-speed subsystems measure island parameters. Off-island measurements of waves and ice forces are handled by two special remote subsystems. These subsystems differ from those on the CRI in that they only collect data at preset scan rates with no in-situ data processing. The use of a local subsystem computer is not possible because of the more severe environmental and power constraints.

The wave measurement subsystem is planned for operation during the summer and fall. This subsystem consists of a number of waverider buoys, to be deployed at the start of the open water season and connected by radiotelemetry to a receiving station in the control trailer. All remote wave data are recorded on separate, dedicated recorders.

The remote ice measurement subsystems are operated only during the winter when an ice field is present. The deployment of three remote ice stations is planned. Currently we envisage that each of these stations will transmit data by a radiotelemetry link to recorders located with the system monitor.

System Monitor

The system monitor is the operator interface to the instrumentation system. Its principal functions are:

- to alert, in real-time, events that may affect the safety of island operations;
- to synchronize and coordinate the activities of the various data acquisition subsystems;
- to maintain an on-line, continuing historical data base of sensor and subsystem performance; and
- to provide on-demand, real-time data summaries, graphical displays and system status reports.

The system monitor consists of another HP9826A computer with its own data tape recorder and a colour CRT display. It monitors the two communication lines from the high- and low-speed subsystems. The tape units shown in the system monitor (Fig. 4) are configured with their input lines connected in parallel so that the HP9826A can monitor the data sent to the recorders by the other local subsystem computers. This configuration preserves the independence of the subsystems and the monitor, and ensures that data are always recorded regardless of the presence or status of the monitor computer. Because the monitor computer also keeps a copy of the data (in summary form) on its own data tape, it provides backup to these data recorders.

Data Acquisition

One of the challenges in designing a data acquisition system is to achieve a balance for the sampling rate, recording time and data storage requirements. This is not always possible because for a fixed data storage capacity the sample rate and recording time are inversely related. In addition, a single "optimum" sample rate may not even exist if the phenomena of interest can have a wide variation in the time periods over which significant changes may occur. For example, the high sampling rate needed to capture peak events (e.g. peak loads or stresses) is extremely inefficient for use during "normal" or slowly varying conditions. Conversely, an efficient sampling rate for the latter is not fast enough to capture these high speed events.

One approach to this problem is to use some form of variable data acquisition rate which is initiated manually or triggered by an event. Although it is easy to adjust the data sampling rate, the task of managing a number of widely differing rates for various sensors under various conditions rapidly becomes extremely complex. Often, it also becomes difficult to identify and retrieve these data, particularly if the sampling rate is manually changed and the means for identification and retrieval are field logs which are subject to human error.

How then can the data acquisition rate be optimized as events occur and the data characteristics change? We adopted a data acquisition scheme in which the data processing and recording is optimized rather than the sampling rate, which is fixed at the maximum required. Averaging and compression techniques are used to reduce this vast amount of initial raw sensor readings to a succinct subset of significantly descriptive data points. The characteristics of the data episode being collected controls the amount of data reduction. A long averaging period is used to produce a low data rate to tape, while a shorter period generates rates approaching the input sampling rate.

The key to the success of this scheme is the identification and characterization of the data episodes to be collected. Our goal is to gather and keep only significant data. Uneventful (i.e. unchanging) data are averaged over a long period and recorded as such.

Episodes having a high information content (i.e. high frequency data such as peak loads and load variations) require a high effective data acquisition and recording rate. This is achieved by reducing or eliminating the data averaging. A number of parameters are used to completely specify a data episode. These include sensor thresholds, data characteristics (e.g. rate of change), timeout intervals, and manual triggers.

This optimization scheme has the advantage of significantly simplifying the control programming for the data acquisition units in the two subsystems. However, implementation of the scheme does require a large amount of processing capacity. This is present in the system design in the form of the combined parallel processing power of the distributed computers.

Finally, this scheme also eases the task of data identification and retrieval because the data processing remains entirely under program control. All processed data are always uniquely defined. In addition, there are no great volumes of normal data to be stored.

Summary

Esso has developed a special instrumentation system for use on its new Caisson-Retained Island, specifically designed to be an unobstrusive, non-interfering partner in island operations. It combines compactness, flexibility and reliability to meet the operational requirements of working in the Beaufort Sea environment.

The system consists of a distributed network of high performance computers and state-of-the-art data acquisition units. The design takes full advantage of the parallel processing power of the distributed computers to achieve high data throughput in combination with in-situ processing. An optimization scheme makes use of real-time data averaging and reduction techniques to effectively manage the data storage on tape.

Acknowledgment

The author would like to thank Dr. J.R. Hawkins, Dr. W. Jazrawi, D.M. Pasenau and K.N. Birch for their review and valuable comments. The continuing encouragement, support and assistance provided by D.A. James is also gratefully acknowledged. Finally, this author would like to express his appreciation to all of the persons who have worked on and contributed to the instrumentation project.

Caisson-retained island for Esso Resources wins top honor

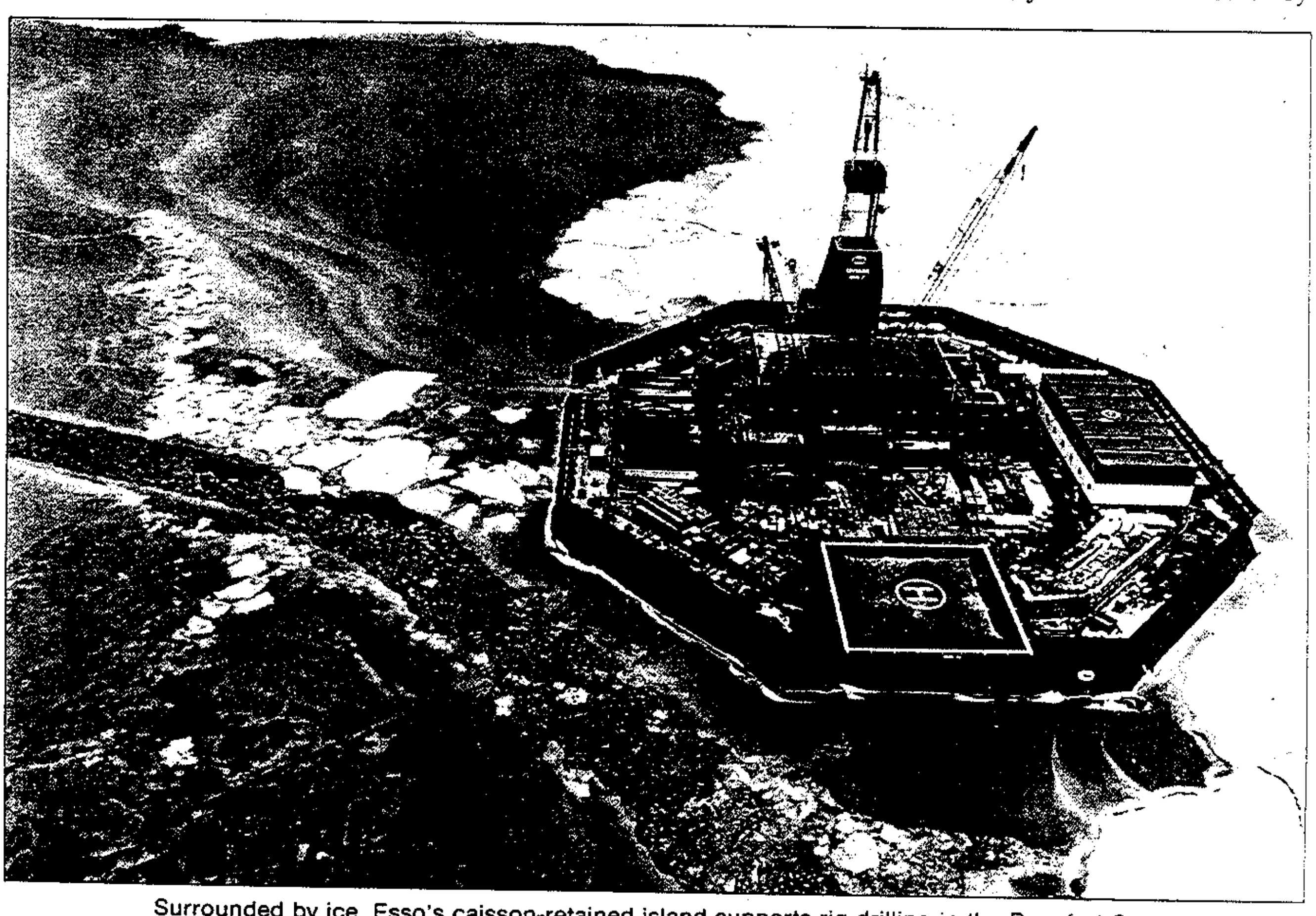
Albery Pullerits Dickson & Associates (1977) Ltd. — Don Mills, Ont.

The first man-made islands in the Beaufort Sea were constructed by Esso Resources Canada Ltd. in 1973 in water two to three metres deep. By 1977 islands were being constructed in depths of 13 to 19 m. Amerk, the latest location, has a depth of 26 m. Used for exploratory drilling, the islands were needed to resist considerable storm wave forces and in winter, to promote sheet-ice failure.

Having long gradual beaches with underwater slopes of about 1:15, these artificial islands use enormous quantities of hydraulic fill. The largest of these islands, Issungnak, which sits in 19 m of water and took three seasons to construct, required 4.9 million cubic metres of fill. The in-place cost of the dredged material at Issungnak was about \$12/m^3. This cost increases substantially, however, when an island site is remote from suitable fill material, making this type of island uneconomic in areas with a clay seabed.

As exploration moved to areas of poor borrow potential, it became necessary to develop a new design for man-made islands. The firm of Albery Pullerits Dickson & Associates was retained in 1976 by Imperial Oil Limited to investigate various concepts for islands that could both meet environmental conditions of the Beaufort Sea and be built at competitive costs. The reusable caisson-retained island (CRI) concept was developed jointly by APD and Esso's engineering group. Detailed design for the CRI was done by APD. Fabricated in Japan from Canadian steel, the caissons were delivered at Tuktoyaktuk in August 1982 for deployment during the 1983 season.

The CRI consists of eight caissons connected to form an octagon with an outside diameter of 117 m. Each caisson is 43 m long, 12.2 m high and 13.1 wide, joined to each other by



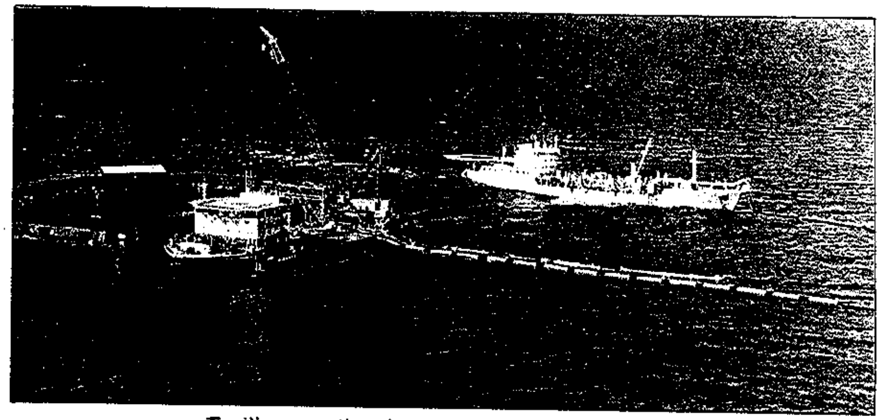
Surrounded by ice, Esso's caisson-retained island supports rig drilling in the Beaufort Sea.

vertical couplings which provide articulation during consolidation. The caisson ring is stressed by two prestressing bands, each comprising eight 75-mm dia. wire ropes. Ballasting and deballasting within the individual caissons raises and lowers the total structure. Four diesel generators located in alternate caissons provide power for hydraulic pumps, hydraulic deck winches, water pumps and ice-melting equipment.

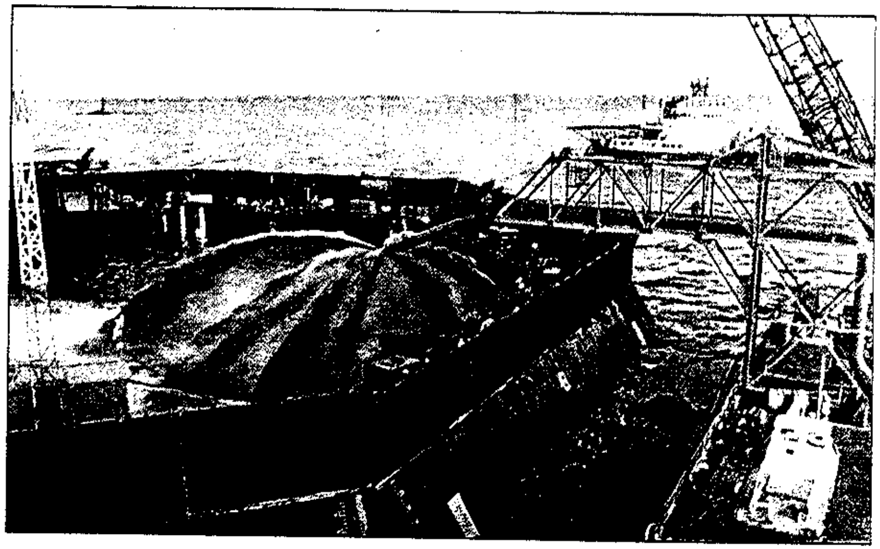
The CRI is designed for a set-down depth of 9 m on an underwater berm with a freeboard of 3 m to the caisson deck. For deployment, the CRI is destressed, raised by de-ballasting and uncoupled into two halves. It is then re-assembled into the ring, prestressed and towed to the new location.

The caisson-retained island represents an innovative, imaginative and economical solution to engineering requirements in the severe environment of the Beaufort Sea. The concept, which uses natural materials to provide a working area and stability against ice shear, cuts down the amount of dredged sand needed by about 75 percent, thereby reducing offshore work and construction time. The resulting cost savings help make offshore exploratory drilling economically feasible.

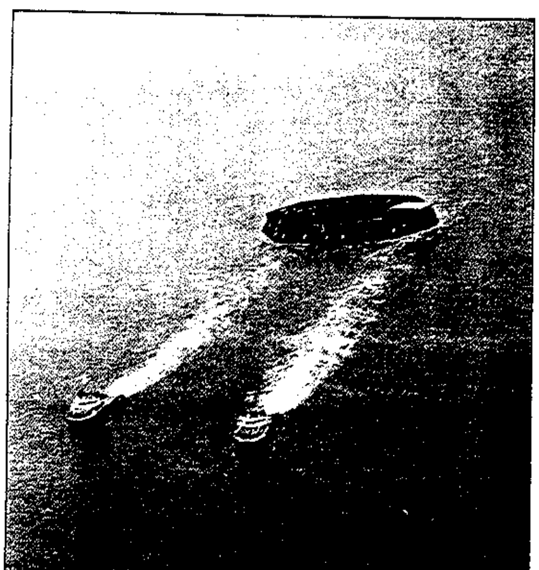
On July 23, 1984 the caisson-retained island was raised from its location at Kadluk and towed to Amerk, north of Kugmallit Bay on July 30. The second well was spudded on August 24. All CRI systems functioned as designed and the tasks of raising, towing and resetting were accomplished as planned. The CRI project is indeed a tribute to the talent and ingenuity of Canadian consulting engineers. □



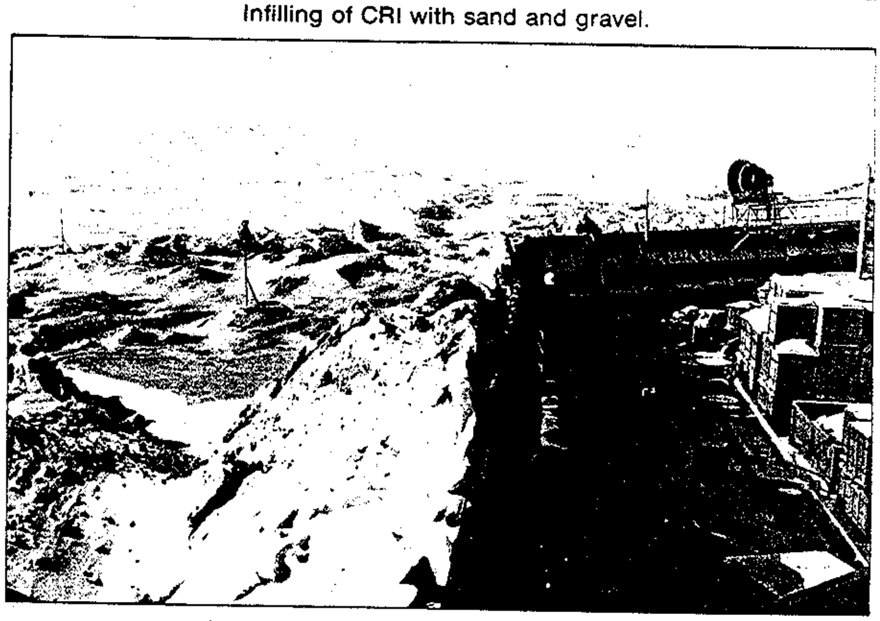
Trailing suction hopper dredge infilling CRI.



Infilling of CRI with sand and gravel.



Assembled ring under tow to first drilling site.



Ice rubble to top of deflectors and above.

CAISSON RETAINED ISLAND (CRI)

THE FIRST YEAR OF OPERATION

M.I. COMYN

ESSO RESOURCES CANADA LIMITED

ABSTRACT

This paper describes the CRI briefly. It follows the sequence of caisson operations from leaving its winter mooring, through initial set down, a winter drilling season, lift off and relocation at a new site. Design features which facilitated these operations are highlighted. The behaviour of the structure under environmental loading is discussed. It is concluded that the CRI is an operational success.

INTRODUCTION

The Caisson Retained Island is a platform for an exploratory drilling rig. The artist's conception is shown in Figure 1. A steel retaining structure is founded on a berm constructed of sand dredged from the seafloor. The inner space is filled with dredged sand, and onto the resulting surface is placed the drilling rig, camp and all necessary supplies.

The steel structure consists of eight caissons, each measuring 160 feet long, 43 feet wide, by 40 feet high. These contain mainly ballast tanks, but integral fuel tanks and machinery spaces are also housed. The unique feature of the design is that the eight caissons are held together by bands of steel wire ropes which are tensioned by hydraulic jacks. The cable forces assist the steelwork to resist the loads imposed by both the retained fill and external forces.

The CRI support fleet consists of a trailing suction hopper dredge (TSHD), used to win sand for the berm and retained fill, and to win gravel for toe protection, a 400 foot construction barge, equipped with a 200 ton marine crane, two 6200 hp anchor handling tugs and a survey vessel. The barge and tugs are built to ASPPR Arctic class 2 standards.

CONSTRUCTION

The caisson was built by Hitachi Shipbuilding and Engineering Company, (now Hitachi Zosen Corporation) as hull no. 1041.

The first steel was cut on 15 January 1985; the first block was laid in the building dock on 28 April 1982; launching was 30 June 1982 and the tow proceeded to sea 4 August 1982.

The caissons being of lesser length than the dock width, could be assembled back to back across the dock. This configuration was very economical of dock space, and contributed to higher productivity of both builders and overseers. The construction employed a total of 420 thousand manhours, with 600 welders being qualified at the peak. The builder, while remaining responsible for schedule and quality, subcontracted to specialized contractors for heat treating, fabrication of components, insulation, painting and the entire helicopter pad fabrication.

As the materials for construction were different from normal shipbuilding steels, all welding processes were prequalified under ABS scrutiny, and every welder was qualified to the procedures that he would be required to use.

Despite the novel design, arctic grade materials, rigorous inspection and a short building period, the construction proceeded very smoothly. While the rapport established between Owner and Builder greatly assisted the process, credit must also be given to the original designers who set the basic parameters that ensured a very buildable structure.

MOBILIZATION

Immediately after acceptance the caissons were released to the towing contractor. Both wet and dry tows had been considered, but dry towing was selected due to low risk to the caissons. Loading on submersible barges was straightforward, and demonstrated the relative ease of handling of the individual caissons, and also the wisdom of keeping the bottoms flat. The tow was conducted without incident. Ice cleared from Point Barrow in time to permit passage, but was encountered north of Barter Island. Slow steaming at short stay brought the barges and cargo through to Tuktoyaktuk without any damage. Following an uneventful unloading the barges were towed south before the ice closed Point Barrow.

The caissons were then assembled into a ring for the winter. None of the yarding tug crews, nor any but supervisory Esso people had witnessed assembly at the builder's yard. It is a tribute to both the design and the people that assembly was rapidly accomplished without untoward incident.

In summary, the design permitted simple mobilization, using existing equipment and techniques that had already become standard. Demobilization, when required, is expected to be accomplished in a similar manner with no difficulty.

WINTER STORAGE

The CRI spent the 1982/83 winter at anchor in the South basin of Tuktoyaktuk Harbour. In the spring some modifications, mainly additional safety items, were installed.

DEPLOYMENT

Shortly after breakup the CRI was towed out of harbour to an assembly area at Tuft Point, a few miles up the coast. The entrance channel is shallow, narrow and not straight. The passage of the complete ring could not be undertaken, but pairs of caissons could be readily handled. In reviewing the possibilities it was found that four caissons could be towed as a unit in "rhombic formation". In this arrangement two tensioned pairs are folded about their common temporary pin, and towed from that point. The overall dimensions were suitable for the channel, so economies were effected in the operation as fewer tugs/trips were required. This type of flexibility is inherent in the design and this is an example of how advantage can be taken of such flexibility.

Re-assembly at Tuft Point again went smoothly. The speed of the operation was limited in this case by the winch operating speeds, which are deliberately low. No changes are contemplated as winch operations are infrequent, but repeat construction would warrant an increase in speed. Final assembly included fitting the helipad. Two lifts of 45 tonnes placed the substructure in sections. As a minor swell was running, difficulties in precise placement were blamed on relative motion between the crane barge and the CRI. It was later discovered that minor faults in the crane control circuits were the trouble. We now intend to leave the helipad installed unless caisson no 3 (on which it rests) requires to be handled individually for repair or other reasons.

A complete testing programme was undertaken which demonstrated system performance after the winter storage, provided operator training, and gave confidence for the set down operation. Among these was stressing to the final value of 800 tons. This was maintained from then on.

The two 6200 BHP tugs were independently connected to the towing clenches by 2" tow wires for the tow to Kadluk. A steering tug was also connected to the stern for manoeuvring only at departure. The weather was calm and the tow uneventful. The caisson towed smoothly at 15 foot draught and did not tend to yaw. A speed of 3 knots was averaged at about 3/4 power.

On arrival at the site the caisson was boarded by the deck crew and surveyors. Quick checks between the survey vessel and caisson showed that the positioning system was tracking. The mooring lines were taken away one at a time to the preset moorings and connected. The evolution took slightly longer than expected, due to the slow speed of caisson winches and the relative lack of slack cable in the moorings. Once all lines were connected the moorings were tensioned up to about 30 tons each. The positioning system was used to compare actual (computed) position to desired position. A colour monitor displayed both positions in realistic plan view graphics. Although regarded with some scepticism before the event, the instant appreciation of the situation that was obtained, made believers of everyone. With complete control over movement in any direction, and with line tensions monitored it was easy to get positional accuracy within the one metre diametral tolerance that had been specified. Nevertheless, in time honoured fashion, shortly before setting down, the presence of the berm shoulder was verified on all sides by lead line soundings.

Ballasting began when positioned had been achieved roughly, and continued throughout final positioning. Testing had revealed excellent behaviour while ballasting, tilting and deballasting, so no excursions were expected. None were experienced, and the caisson was on the berm, negatively buoyant after six hours.

During the first night a gap of 39 mm opened between caissons 6 and 7 at deck level, and to a lesser extent between caissons 2 and 3 (opposite). This was attributed to one side of the berm being out of level, but could also have been due to differential settlement. The situation was monitored carefully for several days, and was found to remain stable. Cable tensions were not affected.

Before the event, set down had been regarded as a critical operation, but once it had been undertaken the essential simplicity was appreciated. While it remains critical it will no longer be viewed with apprehension. Set down in a significant seaway remains untried.

As soon as set down was complete, the first dredge load of sand was discharged into the centre via floating pipeline and the sand arm rigged on the Kamotik construction barge. Sand was provided from the borrow source and also from a stock pile built adjacent to the berm. Filling is critical as the CRI is vulnerable to wave attack until filled to 60%. The provision of a stock pile was intended to reduce dredge transit times in case of a storm. Filling was interrupted once when a discharge pipeline plugged and sank, necessitating its removal for clearing. By this point the construction crews had developed a high regard for the system. It was viewed as a superior method of island building because there was little danger of erosion and no reversals in progress.

Erosion protection for the toe was placed by discharging gravel through a diffuser section on the dredge discharge. This method was observed to scour as much as it placed, so it was replaced by bottom dumping from the dredge and then from split dump scows, to complete the job. This was the one area where the planned operation was inadequate. Alternate placement methods were proposed by various contractors and the most promising ideas were tested in the Esso model basin. The best method determined by the tests was used in 1984.

Placement of erosion protection material was monitored by stero side-scan and echo sounding which was intended to monitor erosion after storms. Mechanical problems were experienced with the boom and float intended to support the electronics overboard package (fish), which put the entire system into disfavour. However once it was operational, information was available from the echo-sounder, and normal to the sounder track by processing the stereo side scan signals. Hard contour plots can be made after the fact which show areas of scour and accretion, and from which required volumes for repair can be calculated. The weather was so good that no erosion occurred so the system was not tried under design conditions. The results collected have been well received by geophysicists and sonar engineers. (Reference 4 refers).

After the island was complete and the surface levelled the rig, camp and drilling supplies were loaded onto the island by crane. This stage progressed as planned over 18 days.

DRILLING

A single well, Kadluk O-07, was drilled to 3,896 m through the winter 1983/84. An extensive testing programme confirmed the presence of hydrocarbons. Six tests obtained measurable flows of dry gas, the best of which was 408,900 m^3/day through a 45/64 inch choke. Only minor amounts of oil were recovered.

RELOCATION

Rig maintenance was progressed as spring approached, and ballast tanks were thawed using installed immersion heaters. Ice formation in ballast tanks was not as thick as predicted, but melting was much slower. At lift off several tons of ice remained in the tanks.

The rig was dismantled and moved from the island to waiting barges as soon as ice conditions allowed access. In ten days the island surface was clear.

Removal of the steel ring from the sand core had been the subject of speculation all winter. Ballast was pumped from all caissons simultaneously, and was discharged onto the island surface. A shallow depression near the caisson back walls channelled the water to where it would do the most good. After all tanks were uniformly deballasted to a level where the structure was positively buoyant the first sign of movement occurred. Small geotechnical failures occurred at the corner joints, followed by massive piping. As the caisson lifted itself off the berm, the retained fill failed in a classical manner, leaving the central core surrounded by a moat inside the steel walls.

The ring was split into halves by removing the permanent coupling pins from two caisson joints. One half was towed clear while the other half remained anchored to the island core.

It had been intended to tow the halves in rhombic form to the re-assembly site seven miles south in shallower water. This plan was changed to take advantage of the perfect weather and flat calm seas. Re-assembly was effected the same day alongside the construction barge, immediately adjacent to Kadluk.

The caisson was then towed to a pre-set mooring north of Pelly Island for maintenance and inspection. A thorough hull survey, and inspection of stressing cables revealed that the caisson was ready for another site. No structural repairs were necessary.

With the taking in tow for Amerk, the second cycle began. No surprises were expected and none were experienced. Setdown and filling went without incident. At this site water depth is 26 m, and ice is expected to be highly mobile.

Erosion protection was placed by the dredge Cornelis Zanen using the side discharge pipe. This method had been proved in model tests, and required no new equipment or modifications. Placement was fast and effective. Construction progress was monitored using the erosion monitoring equipment. A new monitoring method was commissioned, based on the Mesotech 971 sonar, deployed at each corner from booms. Although once again no extreme storms occurred, moderate weather (Hs = 2.5 m) caused some redistribution of material. This was monitored successfully.

INSTRUMENTATION

A discussion of instrumentation is given by Hawkins et al, reference 3. Briefly the instrumentation includes ice pressure sensing, structural (strain gauge) response, geotechnical sensing, and various meteorological instruments. Channels are also provided to give miscellaneous readings such as stressing cable tensions and mooring forces. The system is monitored by a data acquisition system which scans the sensors, notes their readings and records them. As some data are suspected of having rapid transients, such as ice forces, wave forces and structural response, and others, such as pore pressures, are known to have slow rates, the acquisition system is divided into a high speed system and a low speed system. The high speed system scans at 1560 samples/sec while the low speed system scans at one tenth that rate. The data acquisition system is based on Hewlett Packard 9826 computers, and has the capacity to compress data before recording. In this way uninteresting or uneventful data is suppressed, and the interesting events highlighted.

The acquisition system is monitored by a separate computer mounted above deck in the control cabin. This system is used to generate the alerts and alarms, and to make the system daily reports. Over-seeing this system is a human operator who has been a necessary part of this system. His functions have ranged from repairing defective components to interpreting the data collected. We have found that remotely collected data requires a human interpretation of related events. It is also very reassuring to the Superintendent to have a knowledgeable interpretor on site when things get exciting.

ICE RESISTANCE

An unusual ice year was experienced in 1983. The polar pack did not recede as far as usual, and a tongue of second year ice, with some multi-year ice entered the area in late August. This did not impede operations, on the contrary, the absence of waves must have assisted crane operations. An early freeze up in late September caught the old ice inshore. Sufficient amounts grounded to lock the new ice in place as it formed. Early season mobility of new ice was inhibited so that rubble fields did not grow as expected.

On 6 January 1984, a massive ice movement occurred during which a large proportion of the land fast ice fractured and moved northeastward. The thick sheet ice moved against the CRI and the nearby relief well ice pad. Ice rode up the caisson, coming up to 3 m above the deflectors and damaging one of the flare booms. A small amount of ice fell onto the caisson deck. Rubbling occurred as the combination of the flexural failure and the backward deflection took effect. A strongly grounded rubble field grew rapidly away from the caisson. The force of the event was not measured precisely as the best positioned sensor was defective, but readings from an adjacent sensor suggest only modest forces were encountered. No structural damage was sustained, as far as can be ascertained, and no deformation of the fill occurred. The event being so well resisted, despite the frightening speed of events, did much to enhance crew confidence in the system.

Performance in this regard has been excellent to date with all ice loads resisted without trouble. The design loads have not yet been encountered as might be expected.

STRUCTURAL

Strain gauges were positioned on four main frames oriented to see maximum ice loads. The actual locations were selected using a finite element model. Throughout the winter, the stress levels were reasonable. Even during break-up, when some of the largest in-plane ice sheet were measured, structural stresses were low.

GEOTECHNICAL

The behaviour of the retained fill is most vital to the drilling rig. Movements have been negligible and settlement has been slight. The system is therefore perfectly acceptable for the operation. Penetration of frost into the retained fill was monitored as it is a necessary part of the structural finite element model. The initial penetration was slower than predicted, due to above average temperatures in November 1983. After that penetration reached normal levels.

WAVES

The 1983 construction season was very calm. The largest significant wave height recorded was 2.25 m (Reference 5). There followed an equally calm 1984 season. The structure has therefore not been tested in a heavy wave environment and we have yet to learn the effects of wave impact, run up and overtopping, and of the full scale erosion rates.

COSTS

Being a durable asset, the CRI will cost less if depreciated over a large number of wells. For our current exploration programme the caisson and rig is written off over three wells. While we do not wish to discuss actual figures here, a recent comparison with other systems, which included all those now available, showed that the CRI is capable of drilling the cheapest wells in the Canadian Beaufort.

SCHREYER AWARD

The CRI was honoured recently by receiving the top prize accorded engineering projects in Canada. The Schreyer Award, presented for imagination, innovation and excellence in engineering was presented by the Governor-General on 16 October 1984. Not only the consulting engineers, but all who have played a part in bringing this endeavour to fruition should be very proud of their accomplishments, which were truly recognized by this award.

CONCLUSION

The CRI has been proved to be an effective design, which can be operated economically in the Canadian Beaufort. More remains to be learned from it, but it has already demonstrated performance according to our expectations. It has permitted drilling in areas hitherto inaccessible, and will provide knowledge necessary to operate permanent production structures.

ACKNOWLEDGEMENT

We are indebted to Stan P. MacKay, under whose leadership the CRI concept was developed, and without whom the CRI would never have been built.

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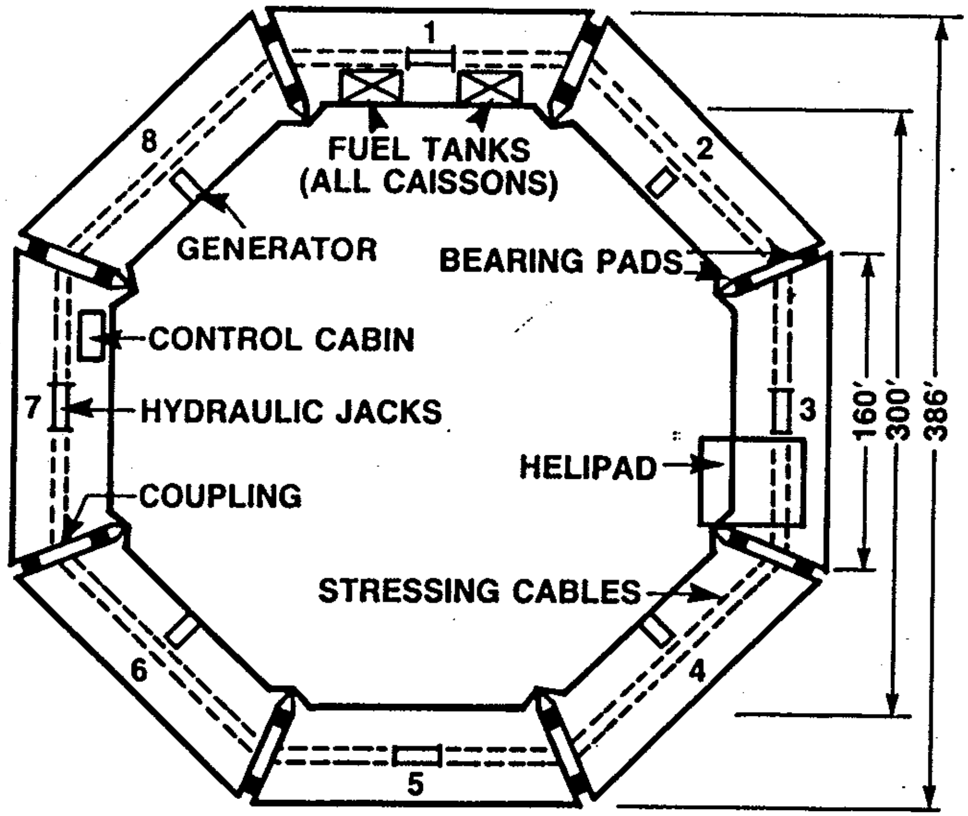
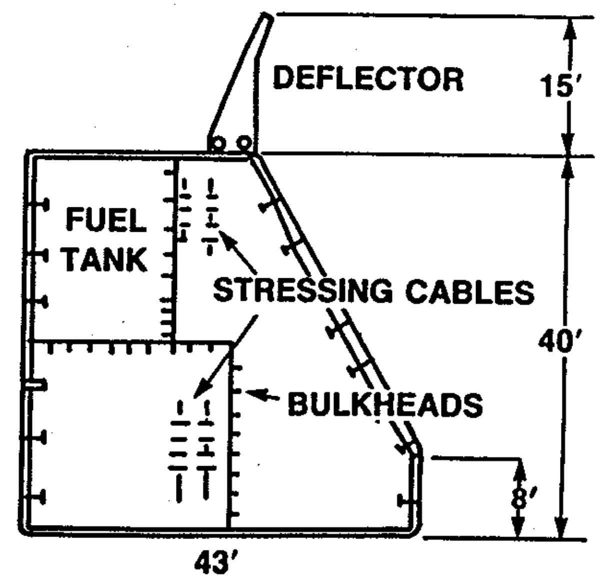
5. L.G. SPEDDING. Kadluk Wave Rider Buoy Data (MEDS Station 208) Measurements Logged by Esso from 83 08 24 to 83 09 08.

53-412

GENERAL ARRANGEMENT PLAN





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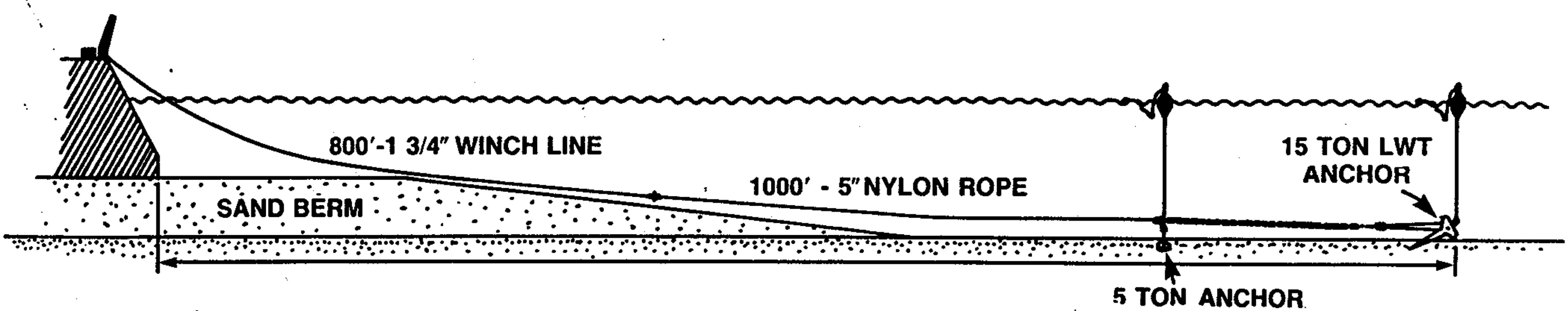
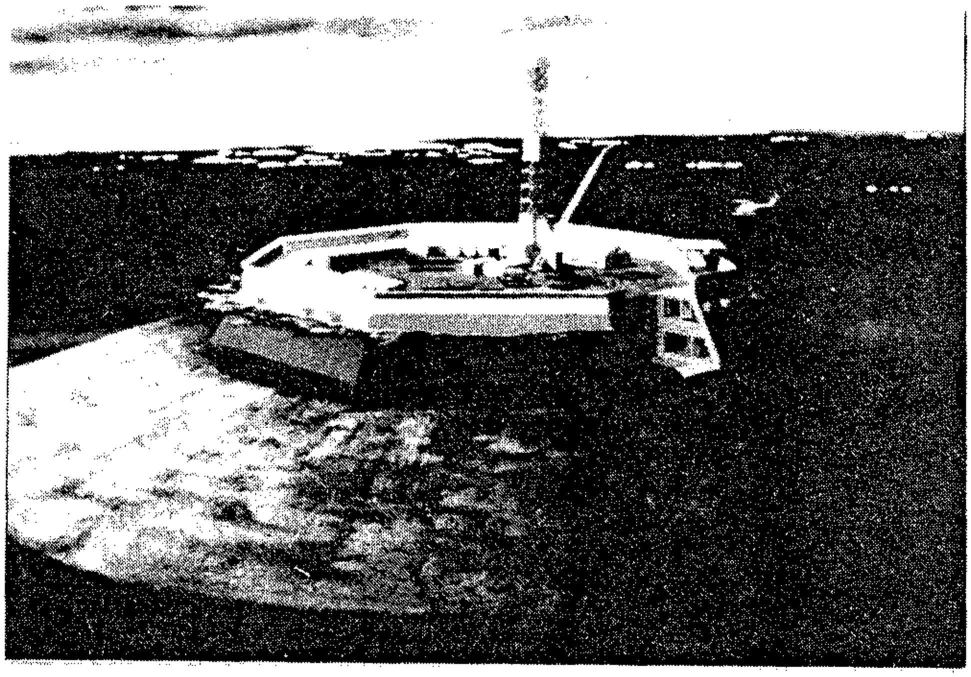
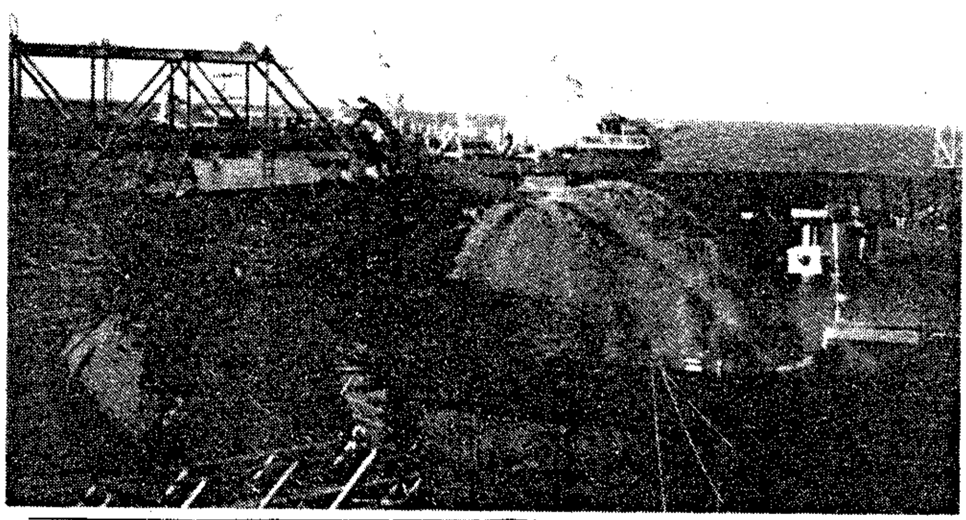
ON SITE CAISSON MOORING

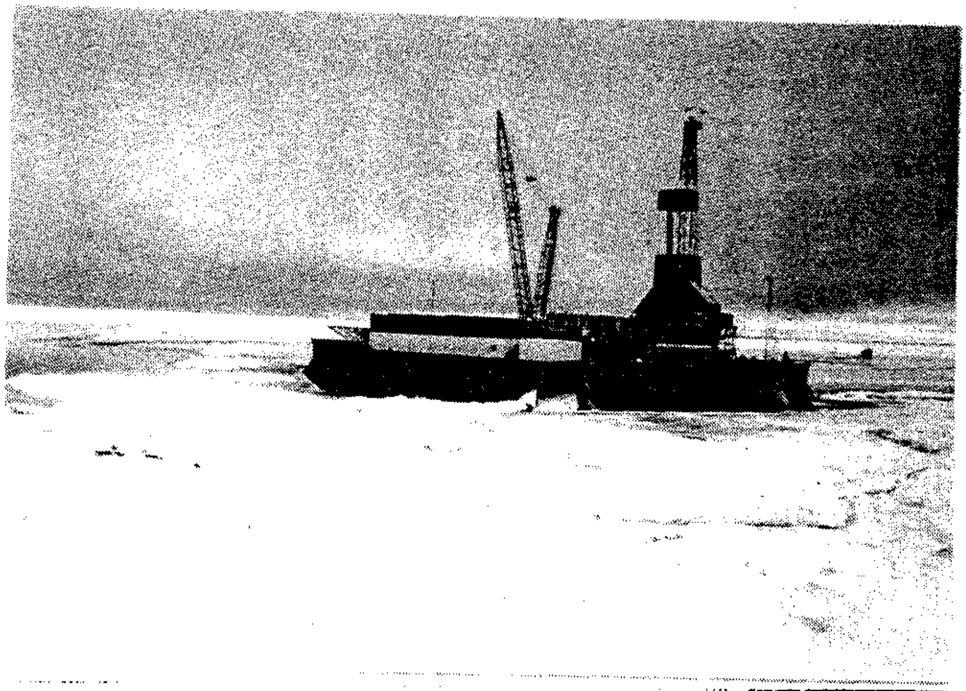




ARTIST'S CONCEPTION. Cutaway steel structure, sand berm foundation, and sand fill.

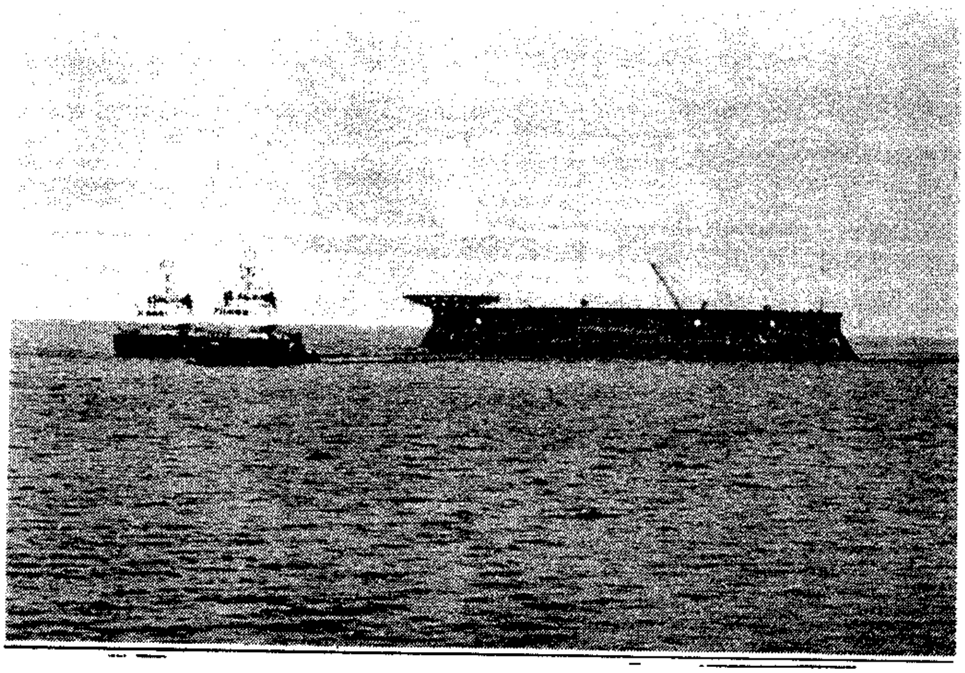


INFILLING. Dredger "W.D. Gateway" pumps sand through floating pipeline and sand discharge arm.

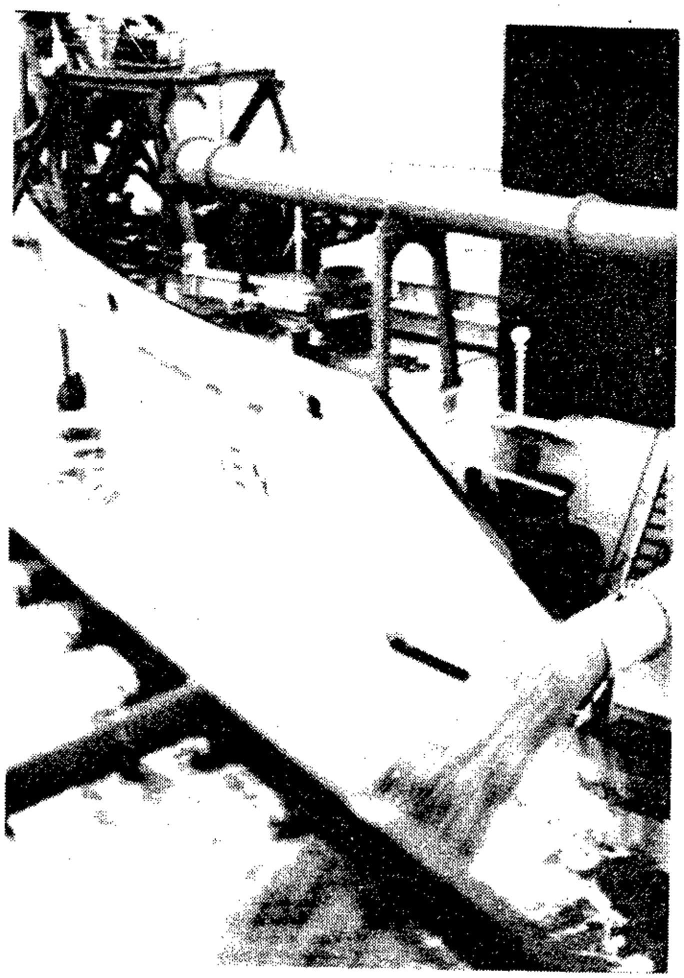


DRILLING KADLUK. **Esso caisson Rig No. 7, locked in ice.**

LIFT OFF. **Pumping ballast raised CRI allowing retained fill to flow out under caissons.**



TOWING. Tugs tow caisson to new location.



TOE PROTECTION. Manoeuvring close to CRI Dredger "Cornelis Zanen" places gravel to prevent erosion at toe.

APPENDIX B

Specification for the Sensors

and Data Acquisition System

HEX PACK ICE LOAD PANEL

Principle of Operation

The Arctec Hex Pack Ice Load Panel comprises two parallel aluminum plates (the load distribution plate and the base plate) separated by a special precision formed aluminum membrane. The individual sensing unit consists of a load button structure formed in a closest packing hexagonal array.

The continuous aluminum honeycomb array is bonded to both the load distribution and base plate. The strain gauge array is wired together into a full bridge to allow measurement of the overall load on the panel with temperature compensation.

The envelope is welded around the periphery to form a water tight seal. Edge stiffness non-linearities are avoided by the location of the strain gauge array within an area more than one characteristic length from the edge.

The panel design stiffness of 240,000 psi sits in the middle of the expected ice elastic modulus range of 150,000 to 600,000 psi, making the panel design optimally suited for embedded sensor deployment within the ice pack itself, as well as mounting to structures. The wide variation of design parameters - membrane thickness, steel aluminum alloy type, load button symmetry, array packing density, base and load distribution plate thickness - allows this panel design to be fine tuned to meet any stiffness specification within the ice range.

Excitation and signal cabling of specified length is carried through a sealed connection in the back or top of the panel at the specified location, with a fitting provided to enclose the cable inside an armored hydraulic hose. This umbilical guarantees the exclusion of seawater, even under pressure, from the panel and cabling and protects against abrasion or physical damage.

The rugged all aluminum construction, highly linear strain gauge sensing, and tremendous design flexibility of the hexagonal packing array make this a highly desirable sensor type, with none of the external fluid lines or elastomeric button creep problems of competitive panel types.

Options: The Hex Pack concepts can be used to produce two different types of sensors.

a) Strain Gauged Average Pressure Transducer (as described above).

b) Strain Gauged Load Profile Transducer.

b) Strain Gauged Load Profile Transducer: The ability to measure total pressure on the sensor plus vertical load distribution is achieved by dividing the sensor into horizontal strips with each strip gauged and wired in a full bridge configuration.

ARCTEC CANADA LIMITED

Specifications:

TYPE:	Arctec Hex Pack Ice Load Panel
DIMENSIONS:	0.25 SQ. m. to 3 SQ. m.
TYPICAL THICKNESS:	22 mm
EXTERIOR FINISH:	1 coat Zinc Primer 2 coats Marine Epoxy

Sensing Element:

TYPE:	Bonded Strain Gauge Array
BRIDGE TYPE:	Fully active four arm Wheatstone Bridge
ELECTRICAL CONNECTION:	Arctic marine grease filled cable inside armored hydraulic hose.

Typical Ice Load Panel Ratings:

RATED PRESSURE:	400 psi (2.8 Mpa)
MAXIMUM PRESSURE:	600 psi (4.1 Mpa)
RATED OUTPUT:	3.22 mV/V
SENSITIVITY:	1.164 X 10^{-3} mV/V Kpa
NON LINEARITY:	0.34% Rated Output
REPEATABILITY:	0.87% Rated Output (at 140 Kpa) 0.52% Rated Output (at 689 Kpa)
HYSTERESIS:	0.5% Rated Output
ZERO RETURN:	0.1% Rated Output
TEMPERATURE EFFECT ON ZERO BALANCE:	0.049%/°C
TEMPERATURE EFFECT ON SENSITIVITY:	0.017%/°C
EFFECTIVE MODULUS:	1540 Mpa (nominal)
CREEP:	0.12% Max. Rated Output (18 Hr. Test)

NOTES: SPECIFICATIONS COMPLY WITH SAMA STANDARD PROCEDURES

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16, 6325 - 11th Street S.E.,
Calgary, Alberta T2H 2L6
CANADA
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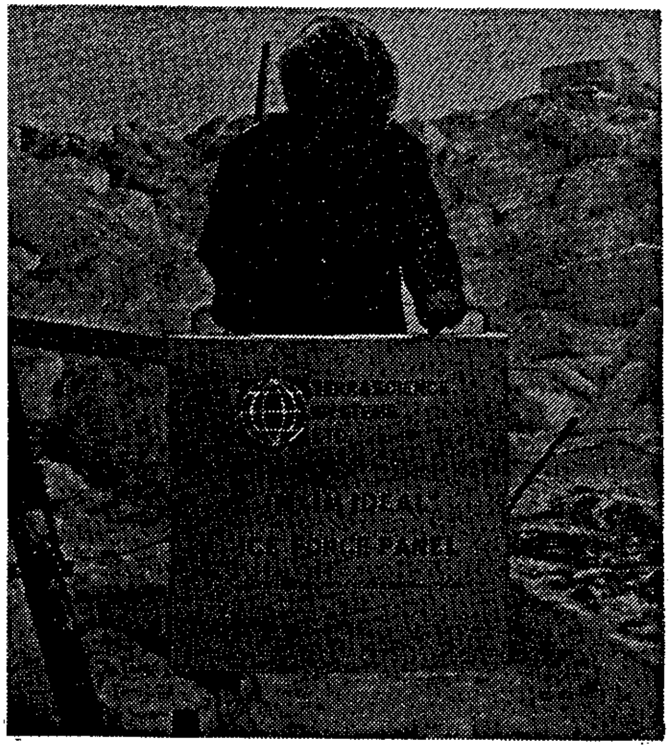
Tlx: 03-821972

TERRASCIENCE SYSTEMS LTD.

1574 West Second Avenue
Vancouver, British Columbia
Canada V6J 1H2
Telephone (604) 734-3443
Telex 04-54224

Manufacturers and Distributors of Instrumentation Equipment

IDEAL* ICE FORCE PANEL



Over a period of almost two years Terrascience Systems Ltd. has designed and tested a new ice force panel which offers significant improvements in both performance and utility over units which are currently available. The Integrated Deformation Elastic Alloy Laminate, IDEAL*, ice force panel has been designed to provide a reliable and cost effective means of measuring both short and long term changes in ice load in a wide range of situations.

The IDEAL* panel offers the following significant features:

- Excellent linearity and repeatability between 0 and 14 MPa
- Insignificant thermal drift between -60 degrees C and +20 degrees C.
- A rugged, hermetically sealed, corrosion resistance design
- Unaffected by differential or impact loads
- A high effective modulus, over 20,000 MPa
- A design which permits easy adaption to different mounting geometries

* IDEAL - Registered Trademark of Terrascience Systems Ltd.

Design Parameters

In order to provide reliable engineering and scientific data about the magnitude and distribution of ice loads an ice force panel should possess specific mechanical and physical properties. These fall into two categories, properties having a direct bearing on system performance, and those contributing to convenience of use i.e. essential and desirable properties.

Essential Properties

(1) Wide static and dynamic range, greater than 0 - 10 MPa (0 - 1450 psi).
(2) Thermal stability of both zero drift and output sensitivity should be less than +/-5% of Full Scale Output over the temperature range -40 to +10 degrees C.
(3) Repeatability of output under specific loading and temperature conditions should be within +/- 5%.
(4) Hysterisis should be minimized between loading and unloading conditions.
(5) High effective modulus - in order to respond to stress variations in the ice, the effective modulus of the panel should be at least 18,000 MPa (2.6 x 10^6psi).
(6) Long term stability - variation in output under constant load should be less than .05% FS/24 hrs.
(7) Corrosion and water resistance - the unit must be unaffected by immersion in salt water.
(8) Portability - the units should be of a weight that can be handled by two men .
(9) Robustness - the unit should be designed so that it is unaffected by the handling typically encountered in the transportation and use of equipment of this type.
(10 Differential Loading - the panel should be unaffected by loadings of between zero and the maximum over areas of less than 10% of the panel surface.

Desirable Properties for both 'In-Ice' Deployment and Structural Mounting

(1) Easy interfacing with commercially available data acquisition systems.
(2) Ability to operate unattended for long periods of time.
(3) High level output.
(4) Ability to either integrate or discriminate load over entire surface area.
(5) Wide range of sizes and shapes.

Additional Desirable Properties for Structural Mounted Panels

(1) Resistance to high impact stresses over partial area - the panel should be unaffected by localized impacts caused by service vessels or wind driven ice
(2) Resistance to shear loads - the panel should be capable of resisting shear loads parallel to the surface equal to 10% of the total load monitoring capacity.
(3) Ease of Mounting - the design should permit mounting on various structures.

* IDEAL - Registered Trademark of Terrascience Systems Ltd.

The IDEAL* ice force panel meets and exceeds all the requirements outlined above, it is easily deployed in rubble piles and on structures, as well as upon level floes.

IDEAL* panels are available in sizes varying from .5m square to 4 ft. x 8 ft., and the standard units are 20 mm (0.8 ins.) thick. Panels having different dimensions, thicknesses, and custom structural mounting hardware are available upon special order.

IDEAL* panels are rugged, corrosion-resistant units, of welded construction, which are helium leak tested prior to delivery. They are available in stainless steel, marine grade aluminium alloy, or marine epoxy coated mild steel.

Particular care has been given to the design of the readout cable penetration system of the IDEAL* panel. The standard panels are fitted with a 6 M (20 ft.) length of Terrascience multi-pair arctic grade grease blocked cable which has a proven performance record on many arctic and marine projects. For added mechanical protection the cable is placed within an armoured urethane hose which forms a further integral seal with the body of the IDEAL* panel. Different cable lengths and termination geometries can be easily incorporated to cater for a clients specific requirements.

The standard IDEAL* panel has been designed to provide an overange capacity of more than 400% without changes in zero, linearity or sensitivity. IDEAL* panels are also designed to survive static or dynamic differential loading conditions where normal stresses of up to 14 MPa (2000 psi) are applied to as little as 5% of the panel area.

A normal stress of 14 MPa will produce an output from the standard IDEAL* panel of 2.33 MV/V. Different outputs can be supplied upon special order with a consequential change in the maximum load bearing capacity of the panel

The IDEAL* panel's maximum design stress of 14 MPa, in conjunction with the resistance to differential loading, has been selected to provide a balance between reasonable output under average ice loading conditions and the ability to measure the peak stresses caused by wind driven floe impacts and supply vessel collisions.

The IDEAL* ice force panel incorporates high strength load carrying modules sandwiched between steel or aluminium panels. Evenly spaced within the load carrying array are a number of equally stiff, but highly sensitive, load measuring modules which sense the external pressure being applied to the outer membrane.

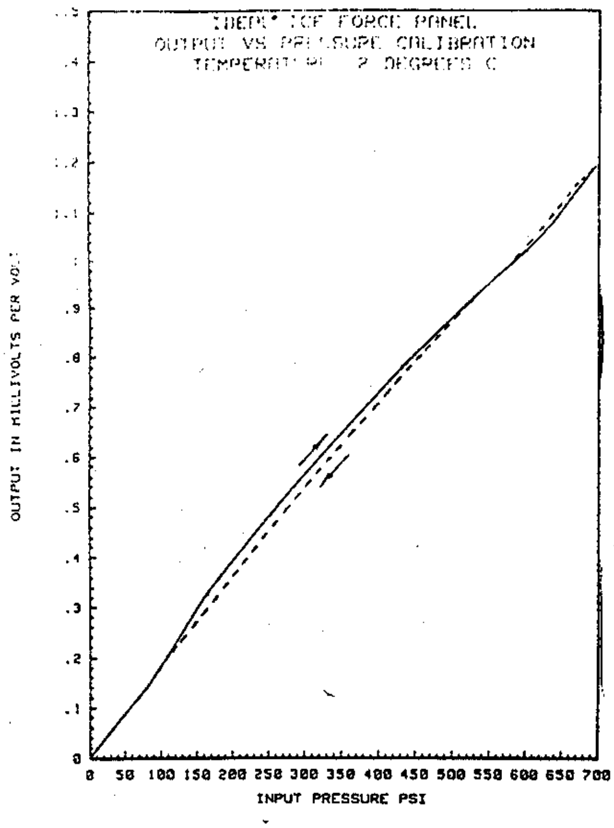
The entire IDEAL* panel is hermetically sealed to prevent the entry of moisture or corrosive agents, it is then welded using TIG techniques to provide shear resistance and additional sealing. Finally the panel is subjected to an extended helium leak test.

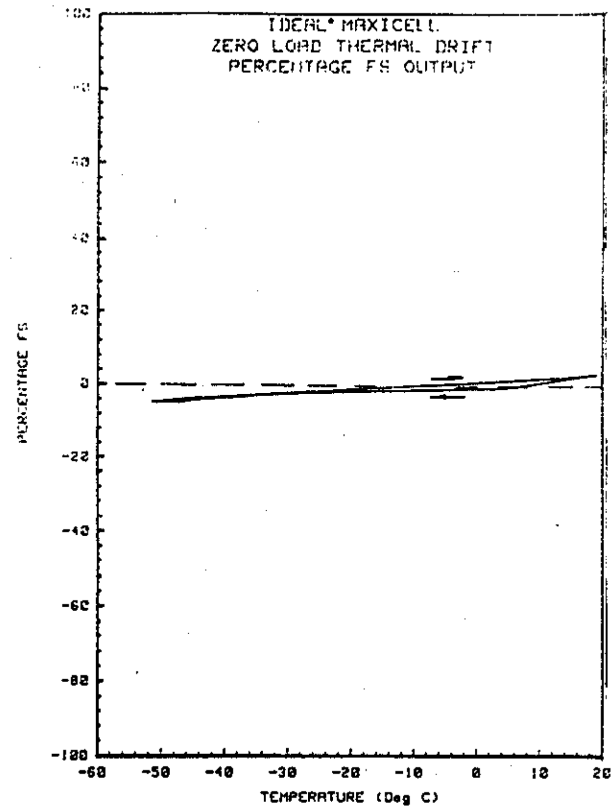
The readout cable for the IDEAL panel passes through a welded and compression sealed entry gland which both provides a completely watertight connection and also functions as a strain relief assembly. As a result of this arrangement the IDEAL panel can be operated in a completely submerged configuration.

The IDEAL* panels has been extensively tested under different loading and temperature conditions and the results of these programmes are available upon request.

Terrascience Systems Ltd. manufactures a range of field deployable data acquisition systems which offer data telemetry or storage capabilities at temperatures down to -45 degrees C. Enquiries for small or large multi-channel data acquisition systems are welcomed, as are requests for custom hardware or software.

* IDEAL - Registered trademark of Terrascience Systems Ltd.





IDEAL* ICE FORCE PANEL SPECIFICATIONS

Dimensions:	0.25 sq. m. to 3 sq.m - 0.5 m x 0.5 m to 4 ft. x 8 ft.
Thickness:	20 mm (0.8 ins)
Exterior Construction:	#316 stainless steel (opt) 6061 aluminium (opt) zinc epoxy coated mild steel (std)
Weight:	60 kgs/m^2 14 lbs/ft^2
Rated Pressure:	3 MPa (450 psi)
Maximum Pressure:	14 MPa (2000 psi)
Output:	2.33 mV/V at maximum pressure
Sensitivity:	.167 mV/V/MPa
Non Linearity:	+/- 3% FS output
Repeatability:	+/- .1% at 3 MPa
Hysteresis:	<.25% FS 0-14-0 MPa
Zero Return:	<.05% FS 0-14-0 MPa
Thermal Effect on Zero	<+/- .07% FS/degree C (-50 to +20 degrees C.)
Thermal Effect on Sensitivity:	<+/- .05% / degree C (-50 to +20 degrees C.
Effective Modulus:	>20,000 MPa (2.9 x 10^6 psi)
Creep:	<0.1% full scale (14 MPa) in 24 hours

Terrascience reserves the right to alter or modify specifications without prior notice.

FOR MORE INFORMATION CONTACT ...

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Terrascience Systems Ltd.
c/o Offshore Instrumentation Services Ltd.
P.O. Box 9100,
Nassau, Bahamas

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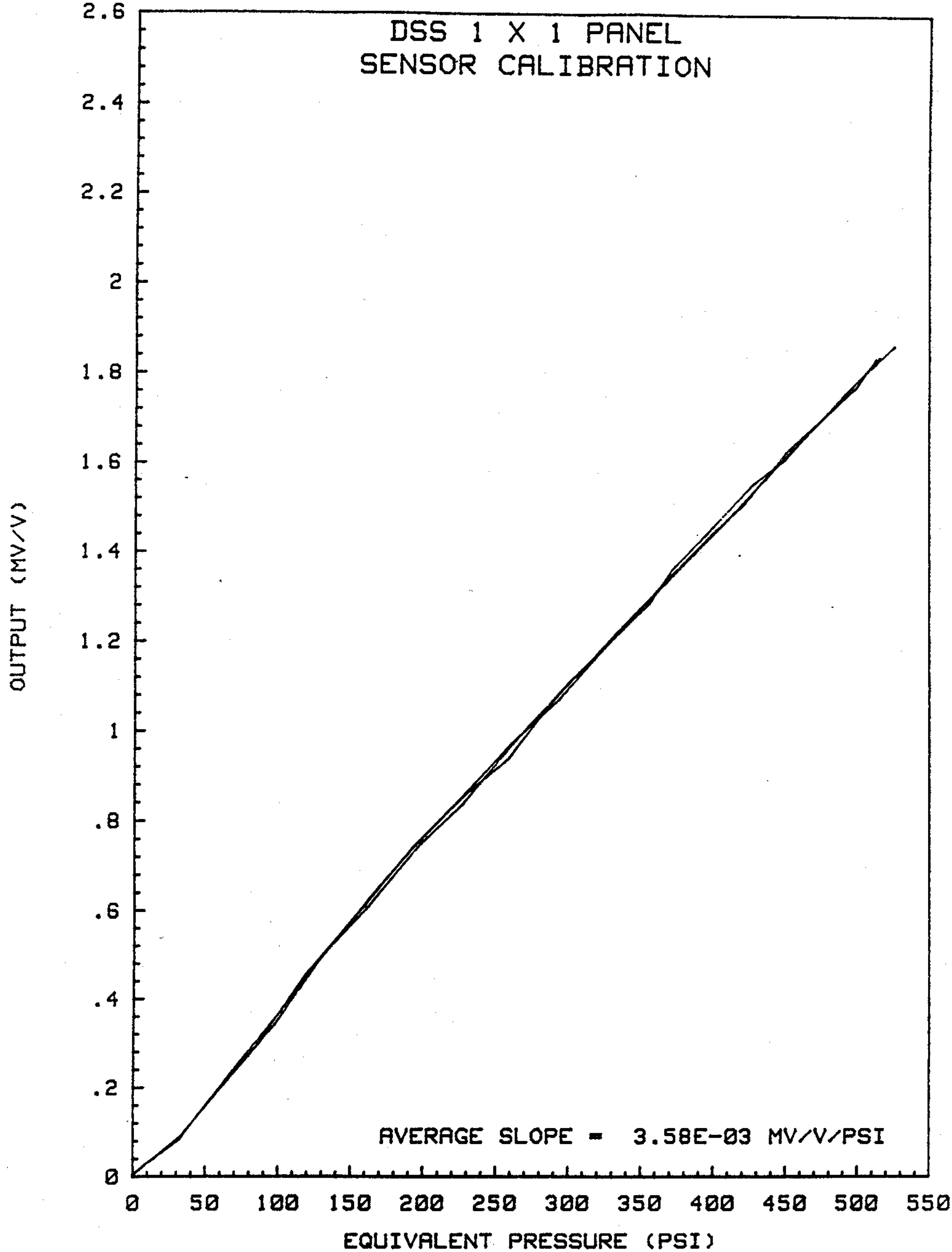
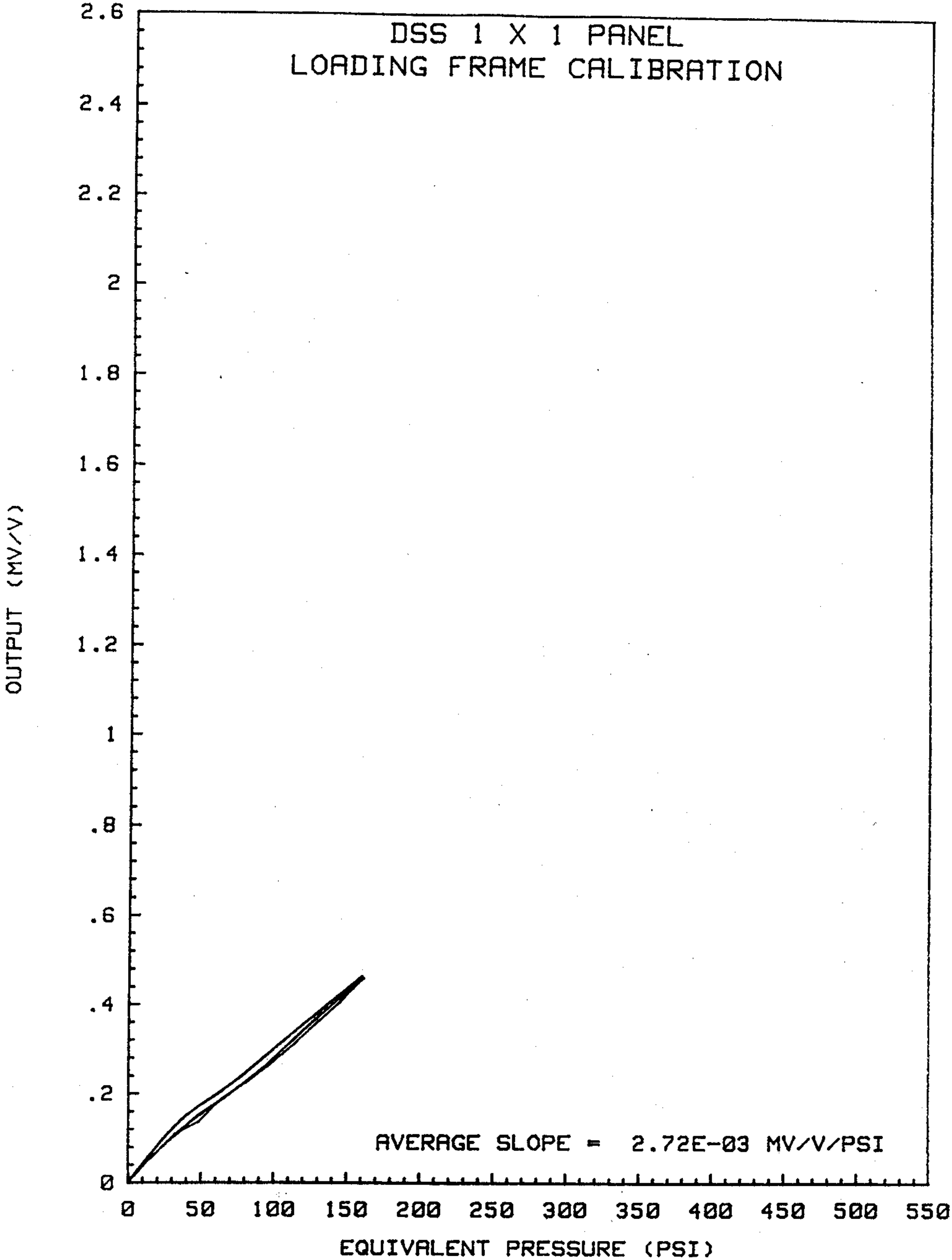

DSS 1 X 1 PANEL
SENSOR CALIBRATION
AVERAGE SLOPE = 3.58E-03 MV/V/PSI
OUTPUT (MV/V)
EQUIVALENT PRESSURE (PSI)
0
.2
.4
.6
.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
0
50
100
150
200
250
300
350
400
450
500
550

83/12/21

83/12/21

DSS 1 X 1 PANEL
SENSOR CALIBRATION

CYCLE 1 PRESSURE (PSI)	CYCLE 1 OUTPUT (MV/V)	CYCLE 2 PRESSURE (PSI)	CYCLE 2 OUTPUT (MV/V)	CYCLE 3 PRESSURE (PSI)	CYCLE 3 OUTPUT (MV/V)
-2	0.00	-2	0.00	-2	0.00
33	.08	33	.09	34	.09
39	.12	70	.25	69	.24
86	.30	96	.35	97	.34
118	.45	134	.51	131	.50
159	.61	163	.63	161	.61
193	.74	193	.74	198	.75
227	.85	227	.85	227	.84
261	.97	259	.94	263	.98
294	1.07	290	1.07	300	1.11
337	1.23	332	1.22	356	1.29
368	1.33	371	1.35	372	1.36
406	1.46	399	1.44	394	1.44
436	1.57	420	1.51	428	1.55
458	1.65	452	1.63	449	1.61
483	1.72	499	1.77	491	1.76
515	1.84	513	1.83	525	1.86


DSS 1 X 1 PANEL
LOADING FRAME CALIBRATION
AVERAGE SLOPE = 2.72E-03 MV/V/PSI
OUTPUT (MV/V)
EQUIVALENT PRESSURE (PSI)
0
.2
.4
.6
.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
0
50
100
150
200
250
300
350
400
450
500
550

83/12/21

DSS 1 X 1 PANEL
LOADING FRAME CALIBRATION

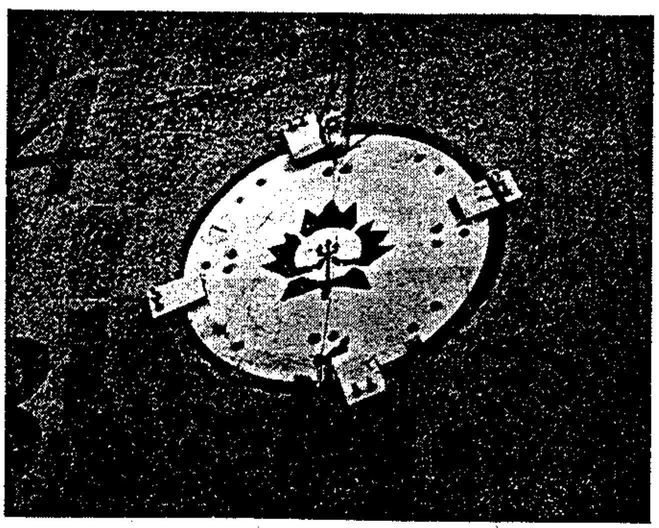
CYCLE 1 PRESSURE (PSI)	CYCLE 1 OUTPUT (MV/V)	CYCLE 2 PRESSURE (PSI)	CYCLE 2 OUTPUT (MV/V)	CYCLE 3 PRESSURE (PSI)	CYCLE 3 OUTPUT (MV/V)
-0	0.00	-0	0.00	-0	0.00
17	.06	17	.06	16	.06
32	.11	32	.11	33	.11
48	.14	48	.15	49	.15
65	.19	65	.19	66	.19
81	.23	82	.23	81	.23
96	.26	97	.27	97	.27
114	.31	113	.32	113	.32
129	.36	129	.37	128	.37
145	.41	145	.42	145	.41
162	.46	160	.46	161	.46
160	.46	160	.46	145	.42
160	.46	124	.37	130	.38
138	.40	106	.32	110	.33
96	.29	73	.23	96	.29
78	.24	52	.18	80	.24
61	.20	37	.14	64	.21
40	.15	15	.07	49	.17
25	.11	-0	.00	32	.13
13	.06			16	.07
				-0	.00

SHEAR BAR ICE LOAD TRANSDUCER

Intended Application of Special Features

The shear bar ice load transducer is specifically designed to measure ice loads on structures generated by encroaching floes. The sensor can either be embedded in structures, if recesses are provided, or fastened to the outside. Its rugged design and many features have made it the most accepted primary sensor in the industry to date. Some of the features are:

- High load capacities 1.75 to 22 MN (200 Tons to 2,500 Tons).
- Large areas: 0.25 SQ. m. to 2 SQ. m.
- Insensitivity to both shear loading and eccentric loading regimes.
- Low profile: 10 cm - 15 cm.
- Environmentally rugged:
  - operates at temperatures of -40°C to +40°C.
  - sealed for continuous salt water immersion.
  - rugged design withstands severe ice impacts.



Principle of Operation

The shear bar ice load transducer is a built up section consisting of front and back plates fastened to an instrumented core. The core is made up with two or four long strain-gauged square bars, precision machined from high tensile steel stock.

The high strength steel used for the bars combined with the support they provide to the plate allows for a low profile of the assembled unit.

Special consideration has been given to the design of the sensor's sealing details; each unit is provided with reliable and rugged primary seals backed by a series of unique secondary seals which essentially makes each bar an environmentally protected unit to the surface. This arrangement greatly increases the cell's probability of survival in the event of primary seal damage.

ARCTEC CANADA LIMITED

Specifications:

TYPE:	Arctec Shear Bar Ice Load Transducer
DIMENSIONS:	0.25 SQ. m. to 2 SQ. m.
SENSOR THICKNESS:	<190 mm.
EXTERIOR FINISH:	1 coat Zinc Primer, 2 coats Marine Epoxy

Sensing Element:

TYPE:	Strain Gauged Shear Bar
NOMINAL BRIDGE ARM RESISTANCE:	4 x 350 ohms
BRIDGE CONFIGURATION:	As selected by client
TEMPERATURE COMPENSATION:	Self compensated gauges; full bridge configuration in standard wiring layout.
ELECTRICAL CONNECTION:	Arctic marine grease filled cable inside armored hydraulic hose.

Typical Ice Load Panel Ratings:

RATED CAPACITIES:	1.75 to 22 MN (Uniform Load)
RATED OUTPUT:	1.75 mv/v at rated capacity (either as individual bars or a full-bridge for entire cell.
SENSITIVITY:	1.56×10^{-3} mv/v/kPa
EXCITATION VOLTAGE:	Norm 10V (Max. 25V)
ZERO OFFSET:	<0.02 mv/v
LINEARITY:	<±2% of Rated Output
HYSTERESIS:	<+4% of Rated Output
THERMAL EFFECT ON SENSITIVITY:	<±0.5%
SHEAR LOAD EFFECT ON SENSITIVITY:	<±2%
POINT LOAD EFFECT ON SENSITIVITY:	<±2%
THRESHOLD LOAD:	<55 kPa
EFFECTIVE STIFFNESS:	2.2 Gpa
FREQUENCY RESPONSE:	Est>20 HZ

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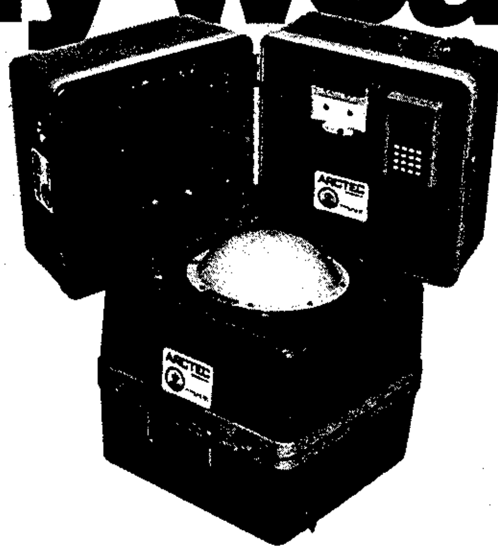
CANADA

Ph: (403) 253-4883
Tlx: 03-821972

now you can capture dynamic analog data in any weather



On offshore oil rigs or in the Arctic cold . . . ARCDATS-1 Data Acquisition and Telemetry System is working actively and accurately wherever *you* can't.

ARCDATS-1 is a new, highly versatile data acquisition and logging system designed specifically for heavy use in *any* remote, hostile, or difficult environment.

Packed with powerful user-features, an ARCDATS-1 unit offers you:

- Up to 75 analog input channels
- Separate per channel gain instrumentation
- Constant voltage transducer excitation
- 8- or 12-bit resolution
- Direct connection to strain gages, thermocouples, RTD's, pressure and displacement transducers, flow meters, and load cells
- Automatic monitoring of excitation voltage
- Automatic power-up/power-down capability for extra long unattended operation
- Dependable Phillips-type tape cassette recorder for data logging
- VHF/UHF telemetry link for multiple master/slave operations

And ARCDATS-1 is all-environment proof, ideal for operations between -40°C and +125°C (up to +60°C for the tape unit).

The entire system is microprocessor-controlled for valuable application versatility. And this compact, light-weight portable unit also features an easy-to-use, pocket size terminal for on-site unit programming.

Designed to answer your on-site needs, wherever you are, the powerful and multifaceted ARCDATS-1 does the job: from Arctic environmental data collection . . . Arctic drilling island ice monitoring . . . Arctic ice road monitoring . . . and tow monitoring . . . to data logging and monitoring of offshore structures and drilling rigs . . . oceanographic environmental data collection . . . hydrological data collection . . . and more.

For the very best in user-features *and* performance — ARCDATS-1 Data Acquisition and Telemetry System is the only all-environment system you'll ever need.

arctec systems™

SPECIFICATIONS

Applications

- Arctic environmental data collection
- Arctic drilling island ice monitoring
- Arctic ice road monitoring
- Tow monitoring
- Data logging and monitoring offshore structures and drilling rigs
- Oceanographic environmental data collection
- Hydrological data collection

System

Microprocessor:	65C02, 8-bit CMOS
ROM:	2 k to 8 k bytes
RAM:	2 k bytes (expandable to 18 k optional)
Keypad:	16-key
Display:	four 7-segment LED
Clock:	crystal controlled ±0.002% accuracy
Power supply:	+7.5 V to +40 Vdc unregulated −7.5 V to −40 Vdc unregulated
Weight:	25 lbs
Dimensions:	13 inches (H) × 15 inches (W) × 14 inches (D)

8-bit Analog-to-Digital Converter

SLAVE UNIT

Channels:	Up to 16
Resolution:	8 bits
Accuracy:	± 1/2 LSB
Conversion time:	60 microseconds
Reference voltage set point:	3.000 volts
Temperature coefficient:	15 ppm per degree C maximum
Excitation	
+:	1.2 to 10.0 Vdc
−:	−1.2 to −10.0 Vdc
Current:	1.5 amperes combined
Regulation:	Line 0.01% per volt Load 0.3% per volt
Temperature range:	−40 to +125 degrees C
Instrumentation amplifier	
Gain:	0.1:1 to 1000:1, programmable
CMRR:	≥110 dB to 40 kHz minimum
Drift:	2 microvolts per degree C maximum RTI 75 microvolts per degree C maximum RTO
Input impedance:	300 megaohms
Non-linearity:	0.1% maximum
Gain bandwidth:	40 MHz

12-bit Analog-to-Digital Converter

Channels:	Up to 8 amplified, plus 8 unamplified
Resolution:	12 bits
Accuracy:	± 1/2 LSB
Conversion time:	100 microseconds
Reference voltage set point:	5.000 volts
Temperature coefficient:	3 ppm per degree C maximum
Excitation	
+:	1.2 to 10.0 Vdc
−:	−1.2 to −10.0 Vdc
Current:	1.5 amperes combined
Regulation:	Line 0.01% per volt Load 0.3% per volt
Temperature range:	−40 to +125 degrees C
Instrumentation amplifier	
Gain:	0.1:1 to 1000:1, programmable
CMRR:	≥110 dB to 40 kHz minimum
Drift:	2 microvolts per degree C maximum
Input impedance:	100 megaohms
Non-linearity:	0.001% maximum
Gain bandwidth:	40 MHz

Recorder

MAST UNIT

Type:	certified Phillips-type cassette tape
Tracks:	2
Density:	615 bits per inch
Format:	dual track complementary NRZ
Write speed:	100 steps per second
Input:	Serial complementary NRZ
Modes:	write only
Step angle:	1.5 degrees
Write head:	dual channel single gap
Operating temperature range:	−40 to +60 degrees C using CAS-2T cassettes
Motor:	Single 7.5 degree angle stepping motor

FM Transmitter

Frequency:	406 to 490 MHz
Channels:	1 (crystal controlled)
Stability:	±0.0005%
RF output power:	2 watts
Transmission rate:	1200 Baud maximum

FM Receiver

Frequency:	406 to 490 MHz
Channels:	1 (crystal controlled)
Stability:	±8 ppm
Sensitivity:	1.4 microvolts maximum wideband SINAD 2.0 microvolts maximum wideband 20 dB quieting
Squelch sensitivity:	0.25 microvolts with tight squelch at 1.8 microvolt maximum
Selectivity:	−70 dB minimum (EIA SINAD)
Rate:	1200 Baud maximum

APPENDIX C

Complete Sensor Records